TOWARDS EFFECTIVE HEAT TRANSITION POLICY IN SOUTH HOLLAND

Comparing a local market driven approach, and a regional plan driven approach for the design of the low-temperature heating system in South Holland, and exploring Q-methodology to design a process of collective learning and decision making between residents and municipalities

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PREFACE

The challenges our society faces in the energy transition and in particular the heat transition, require people that consider the whole system, understand the science, can critically reflect on knowledge claims and complex quantitative models, and put people first. In the past three and a half years, but especially in the last, I have had the privilege to learn from people who are capable of doing this. Thank you Maya, Mark, Laurens, Maarten and Eva for asking the right questions and for making me reconsider my assumptions. Thank you Maya for introducing me to the right people and for your unconditional support. Thank you Mark for creating order in a sometimes messy process. Thank you participants in the Q-study, people from the municipality Zoetermeer, people from the Province South Holland and people from the PBL for taking part in the research and answering all my questions.

I hope and believe this thesis provides reason to reflect on current processes of knowledge development about the heat transition. To acknowledge that there are still many unknowns both in preparation an in organization of the transition processes and to realize that embracing these unknowns can only improve the decisions that are made.

When in I started the double degree in Complex Systems Engineering and Management and Science Communication, I only hoped that the combination of both degrees would bring me where I am today, at the start of an exciting career at intersection of both studies. In the years to come I hope to further grow my knowledge about the heat transition, in particular on the topics of social innovation and low-temperature heating systems, and I hope that I will be able to positively contribute to a successful phase-out of natural gas.

Thank you Micha, Tom, Martijn and Laurens for your positivity towards the graduation process. Thank you Sofie, Clémence, Maaike, Nina and all other people in the SEC graduation room for the team spirit and all the interesting conversations. Thank you Pepijn, for your patience and your loving care. Thank you family, for your listening ear and your warmth.

EXECUTIVE SUMMARY

"Heating and cooling remain neglected areas of energy policy and technology, but their decarbonisation is a fundamental element of a low-carbon economy." (IEA, 2012). With 50% of the final energy consumption, the heating and cooling sector is Europe's largest energy sector. Moreover, 75% of the fuel in the heating and cooling sector in Europe still comes from fossil sources. Reducing the CO_2 emissions from heating and cooling can significantly reduce overall emissions, which is critical for achieving the 2050 goals for CO_2 abatement. In The Netherlands the total heat demand needs to be reduced and the heat provision needs to become more sustainable (Kamp, 2015). By 2021, municipalities therefore need to have formulate plans on how they will realize the phase-out of natural gas in all districts in which the phase-out will take-place before 2030.

The association of Dutch municipalities (VNG), advices municipalities to develop heat atlases as a starting point for formulating environmental plans in which they have to point out in which districts natural gas will be phased out by 2030 and what technology they expect will replace the current natural gas based heating system. Moreover, municipalities look at national and provincial policy to guide decision-making. In South Holland, district heating is considered a cost-effective alternative for the current gas based system. District heating should contribute to the cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. The Netherlands Environmental Assessment Agency (PBL), and the Province of South Holland (PZH), think differently about how district heating should be implemented. It is however currently unclear what these differences exactly are and how they influence municipal policy for the phase-out of natural gas.

METHOD

To gain insights in the differences of these two approaches with regard to the overarching transition objective of cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050, we have developed a conceptual description of both approaches based on literature and consultation. Additionally, we have adapted an existing model of CE Delft, which can calculate the investment costs and fixed costs of district heating infrastructure. We have the removed spatial variation in network design for different consumer groups from the model, as this detailed information is not available. Moreover, we have added the costs for heat storage. The resulting model provides valid initial estimations for the investment costs, without requiring detailed information about the heat demand. A main limitation of the model is that it does not include a NPV calculation, in which the effect of temporal mismatches of investments and returns can be evaluated. The model has pointed out that the investment costs of district heating infrastructure in relation to the total system capacity are sensitive to: the density of the demand, the total heat demand, the detour factor, the length of the primary heat transport network, the capacity of the primary heat transport network and, the total capacity of geothermal heat sources. These factors all relate to the spatial development of supply and demand for district heating.

Furthermore, we have developed a dispatch model that can calculate the performance of a district heating system in terms of CO_2 abatement and marginal costs of heat production. This model was used instead of the NEN7025 norm, which is the current standard for calculating the performance of district heating infrastructure in terms of CO_2 emissions. Other than the NEN7025 norm, this dispatch model includes temporal and spatial mismatches between supply and demand due to production constraints (ramping constraints and maximum production capacity), consumption patterns (weather conditions, heating behaviour, building type and hot water demands) and network constraints (max. capacity and heat losses). Moreover, the dispatch model includes heat storage, which can reduce the use of peak load plants. The dispatch model does not include the effects of the network behaviour, influencing temperature losses, pressure changes and time-delays. The sensitivity analysis has pointed out that the CO_2 abatement that can be achieved through district heating is sensitive to the heat demand for district heat and the availability of low-emission heat sources, such as geothermal heat sources and residual heat.

We have performed a model verification and model validation on both models and we have performed a verification of the input data. The verification of the input data has pointed out that the available estimations of the available residual heat towards 2030 and beyond (CE Delft, PBL, Gasunie and Port of Rotterdam) vary widely and that there are no known estimates for the development of low-temperature heat sources for district heating in South Holland towards 2030. Moreover, the verification has pointed out that there are conflicting ideas about how the total heat demand will develop (Vesta/MAIS and CE Delft) and that the available estimates for the market share of district heating do not provide insights in the actual decision behaviour of residents with regard to district heating. Moreover, the data validation has pointed out that the shape of the shape of the demand-curve is difficult to validate, while it highly influences the system requirements and system performance.

To evaluate the approach of the PBL and the PZH we have developed scenarios for the development of district heating based on these approaches. The PZH communicates openly about these knowledge gaps. In consultation with the PZH, we have selected two highly uncertain data inputs: the availability of geothermal heat and the market share of district heating. Based on these two inputs we have selected three scenarios, representing a low market share (25%) with a low development of geothermal heat (285 MW), a medium-high market share (50%) with a low development of geothermal heat (285 MW), and a medium-high market share (50%) with a high development of geothermal heat (600MW). The PBL however assumes a certain predictability in their forecast, which depend on the Vesta/MAIS model. In consultation with the PBL we have selected three model inputs: a scenario for economic and demographic development (high/low), the CO_2 price in €/ton (10, 37 (default), 50, 100, 150 and 300) and a subsidy on primary heat infrastructure (0%, 10%, 25%, 50%, 75%, 100%). All of these inputs only marginally affected the market share of district heating and the development of the total heat demand. Therefore, we have selected a single scenario for the approach of the PBL. This scenario has a market share of 14% and an availability of geothermal heat of 50 MW.

These four scenarios sketch a picture of what the district heating infrastructure in 2030 could look like if we were to follow their approach. We have analysed these scenarios with the aforementioned models to gain insights in the investment costs, the CO_2 emissions that result from district heating and the cost effectiveness of CO_2 abatement through district heating.

RESULTS

The PBL adopts a local market driven perspective on energy transitions, forecasts depend on the Vesta/MAIS model. The PBL expects that this approach will result in the distributed development of small-scale district heating networks. These networks are scaled to the current demand and have a limited ability to expand over time. The heat in these networks will predominantly come from existing waste-incinerators in Rotterdam and Dordrecht and the gas-fired electricity plants in the region of Rotterdam North. Under current market conditions, approximately 14% of the heat demand can cost-effectively be supplied through district heating infrastructure. In 2030, there is an uneven impact of the transition amongst consumer groups and regions. 32% Of the greenhouses is connected to district heating, followed by 12% utility buildings and finally only 6% of the residential heat consumers is connected to district heating. Moreover, the transition will have the largest impact in the region of Lansingerland, where 34% of the consumers will be connected to district heating and the smallest impact in the regions of The Hague and Dordrecht, where respectively 5% and 6% of the consumers is connected to district heating. These district heating networks require a total investment of approximately 885 million euro and result in approximately 74% CO_2 abatement. Over a period of 30 years, this investment will result in approximately 15 Mton of avoided CO_2 emissions. For each euro invested, approximately 16 kg of CO_2 emissions can be avoided.

The PZH adopts a regional, plan driven perspective on energy transitions, the approach is plan driven and the forecasts depend on negotiated knowledge with large uncertainty margins. The PBL expects that this approach will result in a large main heat transport infrastructure that will make heat from the Rotterdam harbour available throughout South Holland. This heat complements the locally available heat sources. This network is laid out to facilitate the maximum market share for district heating that is technically and financially feasible and societally desirable, to facilitate a full phase-out of natural gas. However, realizing the infrastructure requires upfront demand commitments and initial over investments in the primary heat infrastructure. The PZH is uncertain with regard to the development of demand and available heat of geothermal heat sources, which will influence the final system design. The PZH expects that 25% to 80% of the heat consumers in selected regions in South Holland will connect to district heating. A quick scan of the available supply options and the necessary pipeline capacities to supply heat to the heat consumers in South Holland showed that connecting 80% of the consumers to district heating requires pipeline capacities that seem infeasible in comparison to the currently existing pipelines and pipeline standards. Therefore, we have only looked at scenarios in which a maximum of 50% of the consumers connects to district heating.

The PZH does not distinguish between consumer groups. For now, it expects that district heating will become equally attractive for houses, greenhouses and utility buildings. Moreover, the PZH expects that the development of geothermal heat sources will take off and that there will be approximately 285-600 MW of geothermal heat available. The heat in the district heating system will predominantly come from residual heat from the oil industry in the Rotterdam Harbour and geothermal heat sources. The district heating networks require between 2407 million euro and 4725 million euro of investments and result in 70%-82% CO_2 abatement. Where the CO_2 abatement mostly depends on the availability of zero-emission heat sources in comparison to the heat demand. The investment costs largely depend on the capacity of the system and the number of geothermal heat sources that is connected. Over a period of 30 years, this investment will result in approximately 32-66 Mton of avoided CO_2 emissions. For each euro invested, approximately 13-14 kg of CO_2 emissions can be avoided.

Based on this comparison of the approaches, a trade-off appears between cost-effective CO_2 abatement, and maximizing the overall reduction of CO_2 emissions. In which the scenarios of the PZH in general result in higher levels of CO_2 abatement and the scenario of the PBL is more cost-effective. Additionally, in the light of the full phase-out of natural gas the approach of the PZH appears to provide better opportunities to realize large-scale district heating. The PZH expects that this is a cost-effective alternative for the current gas-based system. This is supported by the analysis, which shows heat supply costs of €36/ MWh in the scenario of the PBL and heat supply costs of €38-42/ MWh in the scenarios of the PZH. While the costs are higher, they do not nearly compare to the 2,25€/m^3 or 230 €/MWh the PBL expects necessary for a full phase-out of natural gas.

FORECASTING METHODS

The identified differences between the scenarios do not solely stem from the PBL adopting a market driven approach and the PZH adopting a plan driven approach. Part of their respective ideas about the development of district heating can be traced back to their methods of acquiring knowledge about the transition.

The PBL has developed the Vesta/MAIS model to predict developments in the heating sector in The Netherlands end to evaluate the effect of changes in market conditions or policy interventions on this development. Currently the PBL also uses this model at a regional (Drechtsteden) and local (Utrecht) scale as a decision support tool for heat policy. The model however, has some limitations that are inherently connected to capturing such a complex optimization problem, with a high level of detail and a long optimization period, in a model. In short these limitations are:

- The drive for completeness has made the model complex and opaque, the model is not user friendly.
- The model has only been subject to limited model validation, while it claims to make very detailed forecasts. At a national scale, local outliers may be averaged out; however, at a subnational scale these outliers are important.
- Optimization of the spatial design of a network is highly complex as it is subject to many degrees of freedom. To make the optimization manageable, the model can only cope with a single type of district heating networks. These networks are initiated in a single district and are based on a single source. Through a search algorithm, the model determines whether adjoining neighbourhoods can be connected. The network can grow up until the maximum capacity of the heat source is reached. The model thus cannot cope with the type of planned, large-scale development of heat infrastructure the PZH foresees.
- The model applies a type of rule based optimization, in which alternatives for natural gas are evaluated in a predetermined order. When a relative cost-advantage is found, the search stops and the alternative

is implemented. Therefore, the model does not necessarily result in a global optimum. Moreover, the model does not provide the user with insights in the relative cost trade-offs that are being made.

- The model has a simplified representation of residential investment behaviour. All investment decisions in the model are consensus decisions at a neighbourhood level, based on complete information and cost-minimizing behaviour, where the current natural gas based heating system is the only frame of reference. These simplifications can result in overestimating actual transition behaviour.
- The model cannot cope with radial technological innovations that may influence the transition outcome.

The PZH collaborates in the Heat Alliance and the knowledge development is process driven. What we know about the approach of the PZH is negotiated knowledge: a form of knowledge that goes through a process of adjustment, consolidation and reconfiguration before it enters the policy process (Littoz-Monnet, 2017). While on the one hand negotiated knowledge is tailored to the informational needs within the policy process, on the other hand negotiated knowledge may lack critical objective reflection. Moreover, it being a process steered by a dominant actor coalition, there is a risk of an unbalanced representation of interests in the acquired knowledge. The available reports on the main heat infrastructure show uncertainty margins, however they do not provide insights in where these margins originate. The forecasts lack insights in the transition dynamics. Additionally, because the acquired data stems from different sources, there is limited insight in the interaction between forecasts and the impact of the limitations of the physical environment on the combination of forecasts.

LIMITATIONS

As discussed in the sections where we have described our research method and the method the PBL and PZH deploy to develop forecasts, there are still many unknowns with regard to the potential for district heating in South Holland. Moreover, the robustness of the available knowledge is difficult to establish. To evaluate the effect of these unknowns on the model results we have performed a sensitivity analysis. This sensitivity analysis has pointed out that the relative advantages and disadvantages of the evaluated scenarios are (nearly) averaged out, when the predictions of the model inputs or the assumptions underlying the system designs deviate with 10% from their estimated value. This shows that the calculated research results highly depend on the accuracy of the estimations based on which the system is designed. The knowledge gaps are thus problematic for municipalities when they are faced with the task of selecting a strategy for district heating. There is a need to develop better, more transparent, estimates with regard to the development of heat sources for district heating. Moreover, there is a need to develop better insights in the demand-side dynamics of the heat transition.

POLICY RECOMMENDATIONS

As we have discussed in the introduction, municipalities currently use heat atlases as an important tool to support the development of environmental plans in which they have to point out in which districts natural gas will be phased out by 2030 and what technology they expect will replace the current natural gas based heating system. These heat atlases calculate the technical and financial feasibility of district heating and other technologies per area, select, and communicate a preferred technology per neighbourhood. As such, these atlases imply certain conditions under which district heat is available. The CEGOIA model of CE Delft, the Vesta/MAIS model of the PBL and the WTA model of OverMorgen are amongst the tools that are being used to develop these atlases.

We know that the CEGOIA model of CE Delft and the Vesta/MAIS model of the PBL have similar outcomes with regard to the potential of district heating. However, these models also have similar model heuristics for the development of heat infrastructure. Moreover, we know that OverMorgen seems to estimate a higher potential for district heat. However, it is unclear where these differences come from and how they relate to the approaches we have discussed in this thesis. The communicative value of these atlases is very strong. In addition, the atlases are very rectilinear with regard to the preferential heat solutions in each district. Especially in this new and vague and complex task municipalities' face, regarding the formulation of transition plans, they provide guidance

However, given the analysis we have performed in this thesis we should re-evaluate the current position of heat atlases in the policy process. The models are a simplified representation of reality and there are so many degrees of freedom when it comes to developing infrastructure that it is a non-linear and non-unique optimization problem. Policy makers should accept that the heat transition is too complex to be fully captured in model-based predictions. Instead, they should become attentive towards understanding the assumptions and the uncertainties that underlie the model results they are faced with, and interpret them in light of the local and regional or national transition objectives.

To support municipal policymaking, I would suggest removing all model heuristics that determine the potential for district heating based on network growth. Instead, I would suggest communicating relevant trade-offs between the alternatives, including but not limited to cost-estimates, and uncertainty margins for each technology per neighbourhood. After which for district heating technical feasibility can be assessed and where relevant a trade-off can be made be between dimensioning to current local demand, and thus controlling investment risk, but also potentially impeding (cost-effective) network growth, or dimensioning to future expected demand, and accepting the risks of over-dimensioning. Here lies a task for governmental organizations, let it be national, provincial or municipal, to co-evaluate the local advantages and disadvantages of both approaches and to potentially mitigate the investment risk associated with the plan based approach.

An important source of uncertainty in both approaches is the extent to which heat consumers are willing and able to participate in the heat transition. Moreover, what aspects of the heat transition they find important and how they will make decisions about the phase-out of natural gas in their home. This source of uncertainty can either be solved by transferring the decision mandate from residents to governments. Alternatively, by developing a better understanding of the needs of heat consumers in the transition and adapting policy processes to match these. The latter we have researched in the second part of this thesis.

RESIDENTIAL ENERGY INVESTMENTS

Literature indicates that for residents to take-action in residential energy transitions, like the phase-out of natural gas, self-efficacy and cognitive dissonance are important factors. In addition, literature indicates that a process of collective learning- and decision-making can influence these two factors as it can provide access to knowledge and resources and, ignite cognitive dissonance, because of interactions with peers and professionals. Effective processes collective learning- and decision-making fit with the participants' problem perception and needs with regard to the organization and content of the process. To design an effective communication-and-decision-making process, it is therefore necessary to develop an understanding of the perspective of residents on these process-design inputs. Therefore, we have evaluated if Q-methodology can support municipalities in developing a better understanding of the needs of heat consumers in the transition adapting policy processes to match these.

We have performed a case-study using Q-methodology in which we have interviewed 14 residents in the district Seghwaert in Zoetermeer. These residents varied with regard to their socio-economic characteristics, their knowledge about the transition and their history in sustainable home improvements. For the Q-study, we have developed a set of statement based on a theoretic framework and a grey literature review. The application of Q-methodological research provides insights in the similarities and differences between multiple resident perspectives on the process of the phase-out of natural gas that can be present within a single district. With the case-study in this thesis we have shown that the application of Q-methodology provides relevant insights in the differences between resident perspectives on the phase-out of natural gas. Even with a small number of participants, and a limited validity of the outcomes, distinctive differences with regard to the problem perception, desired content of the process and desired organization of the process arise.

CASE STUDY

The case study, this has resulted in three narratives describing the problem perception and desired process of the transition, from a resident perspective: 1) The municipality takes the lead, the whole society follows, 2) Individual decisions for a green, clean future, and 3) Waiting for technological progress. Due to a lack of data saturation, we cannot draw definite conclusions about these perspectives. However the largest differences between these perspectives relate to:

1) the innovativeness of the respondent and the risks associated with a fast transition (6),
2) the self-efficacy with regard to decision-making (7),

3) the problem perception and the necessity of the transition based on issues frequently associated with the transition (10),
4) the attitude towards the national transition objective and the perceived forcefulness of the transition (12) and,
5) the attitude towards the national transition objective and the distance between the government and the public in the formulation of transition objectives and organization of the transition (13).
6) the desirability of improvements to the neighbourhood when the streets are opened-up for changes to the infrastructure (22),
7) the expectations towards and desirability of independence of large energy companies (29), and
8) the expected safety and reliability of alternatives for natural gas (34).
9) the prerequisite for the transition that companies and industries also participate (40) and,
10) feelings about the way the timing of the transition should be organized (52).

To assess the relevance of these insights, we have performed a focus group in which we have evaluated the results of the Q-study with policy makers of the municipality Zoetermeer, who are currently engaged in developing a communication-and-decision-making process for the phase-out of natural gas in the district Palenstein. This focus group has pointed out that the type of information the Q-study provides can be used to overcome misconceptions process designers may have about the needs of residents in the transition process. Moreover, these insights can be used to select a local focus for the design of a communication-and-decision-making process about the phase-out of natural gas, which is sensitive to local needs with regard to the transition. The insights in the resident perspective on the transition are not only desirable; they are unobtainable for the municipality Zoetermeer through currently available methods.

INTEGRATION

In the literature review and case study, we have seen that residents adopt a wider set of decision-criteria for energy transitions than is currently reflected in the policy goal. Where the national policy goal entails: cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. The set of values residents deploy in evaluating the heat transition includes: efficient and not wasteful, protection of environment and nature, security and stability, autonomy and power, social justice and fairness and, improvement and quality (Demski, Butler, Parkhill, Spence, & Pidgeon, 2015).

So far, we have predominantly highlighted the learning-and-decision-making processes of residents. However, when we reflect on the transition goal and the set of values residents deploy in evaluating the heat transition, we see that these communication-and-decision-making processes can be of great value for municipalities, and regional governments such as the Province, to guide their own learning processes. Existing methods of knowledge development about the heat transition, let it be modelling or process-driven knowledge development, are not tentative to these values.

Currently, processes of knowledge development about the heat transition are driven by the information needs of governments. However, this does not fit with the mandate in the transition. The application of Q-methodology, allows us to reverse the thought processes about what type of information municipalities need to formulate environmental plans for the heat transition. Rather than answering the question: What is the optimal choice for district heating in this area, based on technical and financial constraints? We can start asking: What information do the residents need to make well-informed decisions in the heat transition? Answering this question results in a demand-driven process of knowledge development, which is more tentative to values residents may find important. This means that current processes of knowledge development can be improved based on the local information needs.

As a result, the risks in the policy process shifts. Where knowledge development initially focussed on realizing the policy target of cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050, at a risk of societal resistance resulting in an incomplete phase-out of natural gas. It now focuses on limiting the societal resistance of the heat transition and realizing a full phase-out, while potentially mitigating the extent to which we are able to realize cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050.

LIST OF DEFINITIONS

The PBL: The PBL is an abbreviation for The Netherlands Environmental Assessment Agency, in Dutch the Planbureau voor de Leefomgeving. The PBL is the national institute for strategic policy analysis in the fields of the environment, nature and spatial planning. It is part of the Dutch Government organisation; more specifically, the Ministry of Infrastructure, Public Works and Water Management.

The PZH: The PZH is and abbreviation of the Provincie Zuid-Holland. The PZH has the official role to coordinate municipal heat plans within South Holland. The PZH works together with public and private parties to prepare business cases for the expansion and interconnection of heating networks in South Holland.

Approach: An approach is a way of considering or doing something. In this thesis, the word *approac*h is used to describe the way the PBL and the PZH develop scenarios for district heating in South Holland. This includes the (actor) processes, methods and assumptions they deploy.

Approach of the PBL: this is a definition used to describe the approach for the development of district heating infrastructure assumed by the PBL in their Vesta/MAIS model.

The approach of the PZH: this is the approach the PZH deploys for developing district heating transport infrastructure in South Holland. This approach is described in policy documents and publications.

Vesta/MAIS model: this is the model developed by the PBL for policy analysis in the heat sector. The Vesta model is the original GIS-based model. The MAIS model represents the extension of the model that includes the division of costs and benefits amongst stakeholders. The Vesta/MAIS model is freely available at: https://github.com/RuudvandenWijngaart/VestaDV/wiki. User-instructions and documentation can also be found on this website.

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1.

INTRODUCTION AND PROBLEM DESCRIPTION

1.1 TOWARDS LOW-CARBON HEATING SYSTEMS

CO_2 abatement is a core issue for the European Union. Towards 2050, the European Union envisions a competitive low-carbon European economy. In terms of policy goals, this means that in 2020, in comparison to 1990, 20% of the electricity should come from renewable energy sources, the greenhouse gas emissions should be reduced with 20% and the energy efficiency should increase with 20%. Towards 2030 the greenhouse gas emissions need to be reduced with at least 40% and towards 2050, the greenhouse emissions need to be reduced with 80-95% compared to the 1990 levels. These levels of CO_2 abatement require far-fetching measures (van Vuuren et al., 2017).

The transport and electricity sector have been important policy focus area's for decarbonizing the European economy since the start of environmental policy. Economic growth is an important driver for greenhouse gas emissions, and decoupling economic growth from emissions is an important challenge in reducing overall emissions. However, despite efforts to reduce greenhouse gas emission, economic growth still pressures the environment (7th EU Environment Action Programme, 2013). Moreover, *''the prevailing model of economic development – based on steadily growing resource use and harmful emissions –cannot be sustained in the long term.''* (European Energy Agency, 2015, p.83). By expanding the policy focus to the heating and cooling sector, new opportunities for decarbonizing the economy arise. "Heating and cooling remain neglected areas of energy policy and technology, but their decarbonisation is a fundamental element of a low-carbon economy." (IEA, 2012). With 50% of the final energy consumption, the heating and cooling sector is Europe's largest energy sector. Moreover, 75% of the fuel in the heating and cooling sector in Europe still comes from fossil sources. Reducing the CO_2 emissions from heating and cooling can significantly reduce overall emissions, which is critical for achieving the 2050 goals for CO_2 abatement (Textbox I)

TEXTBOX I: INTERNATIONAL CLIMATE GOALS

In October 2014, the Member States of the EU reached an agreement about a new climate package for 2030. EU government leaders have committed themselves to the following goals:

1) Reducing greenhouse gas emissions by at least 40 %;

2) Increasing the share of renewable energy to at least 27%;

3) Reducing the total energy use in the EU with at least 27 %.

The objective to reduce the EU's greenhouse gas emissions by at least 40% in 2030 was submitted in March 2015 as the EU's pledge in the run up to the negotiations on a new global climate agreement at the international climate summit in Paris in 2015.

1.1.1 LOW-TEMPERATURE HEATING IN THE NETHERLANDS

At a national level, these European policy targets require significant emission reductions. *"The Paris Climate Agreement, therefore, for the Netherlands, means a 90% to 100% reduction in CO2 emissions, by 2050. This objective can only be achieved if preparation and implementation are realised soon, because it would involve very substantial changes. Only picking low-hanging fruit - easily realised and relatively cheap measures, such as many types of efficiency improvements — will not be sufficient to achieve this objective. Investments over the coming decade already - and to a large degree - determine what the Dutch energy system will look like in 2050. It is therefore important that sufficient investments are made in innovative technologies that, in the short term, are still relatively expensive but will be indispensable in the long term, if the objective is to be achieved."* (van Vuuren et al., 2017, p.24)

In The Netherlands, low temperature heating accounts for 35 Mton of CO_2 equivalent, approximately 17.8 % of the total greenhouse gas emissions (Ministry of Economic Affairs, 2016). The Netherlands strongly depends on natural gas for its low temperature heating. In 2013, 89% of the heating demand of buildings was supplied through individual gas-fired boilers (Tigchelaar & Leidelmeijer, 2013). Natural gas has been an important part of the Dutch energy system since the discovery of the Groningen gas field in 1959-1960. Within 10 years after the discovery of this large gas field, three quarters of the Dutch households had a natural gas connection (installatie.nl, 2016). In 2015, individual condensing boilers supplied 734.7 PJ (figure 1). Most of this heat was produced with natural gas as 99% of the available gas in the Netherlands is natural gas and only 1% is sustainable gas. The sustainable gas in the Netherlands can be subdivided into green gas, which can be fed into the existing natural gas infrastructure, and biogas, which has a different quality and is often used locally. District heating networks supplied 21.6 PJ. District heating networks largely depend on electricity plants that coproduce heat (figure 1). 85% of the heat in district heating networks comes from plants are based on fossil fuel sources or waste processing. Individual heat pumps supplied only 9.6 PJ. These heat pumps consume electricity with a conversion rate of 3 to 5 (1 unit of electricity consumption, results in 3-5 units of heat production). 70% of the electricity consumption in the Netherlands is produced from fossil fuels. From this perspective, fossil fuels also power most individual heat pumps. The whole Dutch low-temperature heating system is therefore very fossil fuel driven. This means that the carbon footprint of the Netherlands can be greatly reduced through phasing out natural gas for low-temperature heating purposes.

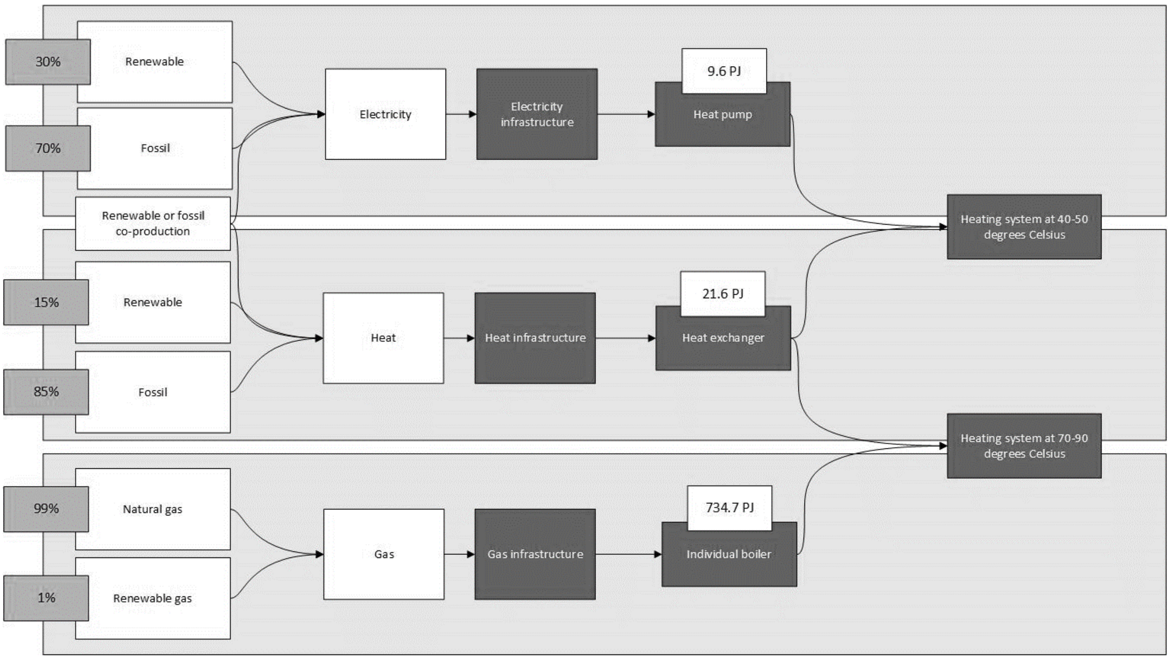


Figure 1 Overview low temperature heating options (Data: (CBS, 2016; Menkveld, Matton, Segers, Vroom, & Kremer, 2017; Ministerie van Economische Zaken, 2016)

1.1.2 RECENT DEVELOPMENTS

Minister Kamp, the preceding Minister of Economic Affairs, announced on the 2nd of April 2015 that the position of natural gas in the energy system must change. The total heat demand needs to be reduced and the heat provision needs to become more sustainable (Kamp, 2015). More sustainable alternatives for low-temperature heating exist. They should be explored more and be more widely applied. Alternatives for natural gas heating include; district heating, heat pumps and green gas. Heat for district heating networks can be supplied by residual heat from industrial processes, by geothermal heat sources, and by heat from the sun, water, and biomass (Kamp, 2015).

Recent developments show that the phase-out of natural gas in The Netherlands has started. Firstly, in November 2016, the municipality of Amsterdam publicly announced the ambition to fully phase-out natural gas by 2050 (Gemeente Amsterdam, 2016). Secondly, on March 8th 2017, the Green deal ''Gas free districts'' was signed by 31 municipalities and 11 other public and private parties. With this Green deal, municipalities commit to appointing one district within their municipality which has a high potential for phasing out natural gas (Ministry of Economic Affairs, 2017). And thirdly, since March 2017 the Province of South Holland collaborates with Port of Rotterdam, Gasunie, Eneco and the Rotterdam Heat Company to investigate the possibilities to implement a province wide heat transport infrastructure (Province of South Holland, 2017c).

On the 3th of April 2018 the political and societal uptake of the transition has led to the installation of the new law for the progress of the energy transition (Wet Voortgang Energietransitie; ookwel Wet VET). The amendment Jetten on this law legislates the end of the "right to a gas connection" which was previously organised in the Dutch Gas law (Textbox II). This is an important piece of legislation for the transition. It sets the new standard for gas-free heating and cooking in newly developed buildings. However, there is no legislation yet that provides similar mandate for the existing built environment. This means that the success of the full-phase-out of natural gas is currently co-dependent on the acceptance and action of residents towards gas-free districts. Where municipalities and companies need develop policy and create alternative options for natural gas, building owners and tenants in the existing built environment currently have the mandate to decide.

TEXTBOX II: AMENDMENT JETTEN

Met dit amendement wordt voorgesteld om:

a. nieuwbouw niet aan te sluiten op het gastransportnet. Op deze hoofdregel kan alleen een uitzondering worden gemaakt als het te bouwen bouwwerk in een gebied ligt dat door een college van burgemeester en wethouders is aangewezen als gebied waar aansluiting op het gastransportnet om zwaarwegende redenen van algemeen belang noodzakelijk is, waaronder begrepen de maatschappelijke kosten en baten, aansluitingen strikt noodzakelijk maakt. Bij ministeriële regeling worden hiertoe nadere regels gesteld;
b. het college van burgemeester en wethouders – in aanvulling daarop – de mogelijkheid te bieden om gebieden aan te wijzen waar geen nieuwe aansluitingen meer komen, omdat daar zich een warmtenet of een andere voor de warmtevoorziening toereikende energie-infrastructuur bevindt of gaat bevinden. Een college van burgemeester en wethouders kan in deze gebieden slechts besluiten tot een aansluiting op het gastransportnet, wanneer zwaarwegende redenen van algemeen belang, waaronder begrepen de maatschappelijke kosten en baten, aansluitingen strikt noodzakelijk maken. Bij ministeriële regeling worden hiertoe nadere regels gesteld.

Stuk 34 627: Wijziging van de Elektriciteitswet 1998 en van de Gaswet (voortgang energietransitie)
Amendement 23: gewijzigd amendement van het lid Jetten c.s. ter vervanging van dat gedrukt onder nr. 19.

1.1.3 MUNICIPAL GOVERNANCE OF HEAT TRANSITION

Municipalities will have the guiding role in the local transition of the heat system. Currently municipalities steer the development of district heating via so-called heat plans. Via these plans, municipalities can demand the implementation of district heating networks or equally sustainable heating solutions in newly build neighbourhoods. Besides this, municipalities can initiate the development of a district heating network as concession provider or contracting party and municipalities can support the development of a district heating network initiated by a private company (Planbureau voor de Leefomgeving, 2017a). By 2021 all municipalities need to have formulated policy for the phase-out of natural gas in so-called environmental plans (omgevingsplan) (CE Delft et al., 2017), which will be a part of the new environmental law (omgevingswet) (Textbox III). However, they will have to function as the basis of local energy and heat policy (Ministry of Economic Affairs, 2016). Municipalities need to explain how and in what pace the phase-out of natural gas will take place within their jurisdiction (Ministry of Economic Affairs, 2016). For all districts in which natural gas will be phased-out by 2030, the environmental plans need to specify the technology that will be implemented.

While these municipal heat plans are instrumental to the phase-out of natural gas, they do further guide municipalities in the process of formulating an approach. It is unclear for municipalities what the exact requirements for these environmental plans will be (VNG, 2017). The formulation of effective environmental plans on the topic of the heat transition is therefore a difficult task. Not only because it is new and the requirements are unclear, but also because policy-making for energy systems requires integration of social, economic and technical knowledge: *"An energy system is a socio-technical system, comprised of more than just pipelines, fuels, and engineering equipment. Markets, institutions, consumer behaviours and other factors affect the way technical infrastructures are constructed and operated."* (Keirstead, Jennings, & Sivakumar, 2012, p. 3848).

TEXTBOX III: ENVIRONMENTAL PLANS

"Gemeenten moeten de regie nemen in de lokale transitie van de warmtevoorziening. Zij kunnen het beste de lokale omstandigheden en effecten inschatten voor de timing en richting van de transitie."(Ministry of Economic Affairs, 2016, p. 67). *"De gemeente legt dit [warmte invulling en besparingsopties] vast in het omgevingsplan dat daarmee ook fungeert als lokaal energie- en warmteplan. Hiermee geeft de gemeente aan op welke wijze, in welk tempo en met welke instrumenten de verduurzaming vorm krijgt."* (Ministry of Economic Affairs, 2016, p. 66) *"Onderdeel van de planmatige aanpak is dat elke gemeente eind 2021 voor alle wijken en gebieden binnen zijn grenzen een plan heeft ontwikkeld waar er wanneer een alternatieve warmtevoorziening gerealiseerd moet zijn."*(CE Delft et al., 2017)

1.1.4 APPROACHES FOR DEVELOPING DISTRICT HEATING IN SOUTH HOLLAND

The Province of South Holland and the Netherlands Environmental Assessment Agency (PBL) aim to support and guide municipalities in formulating their local heat-approaches through information gathering and developing overarching visions for the transition. They fulfil a role in evaluating the options for the regional and national transition of the heating system and formulate overarching transition objectives and pathways.

The PBL is the national institute for strategic policy analysis in the field of environment, nature and (public) space. The PBL is formally a part of the Dutch Ministry of Infrastructure and the Environment. The PBL advices this and other ministries about strategic options for achieving government goals in the areas of environment, nature and space. In this role, the PBL also advices about the development of residential energy systems in The Netherlands, and the role of district heating networks. The PBL expects a local, market driven development of district heating infrastructure and bases its policy advice on this type of distributed network development. To test and evaluate policy measures that could influence the development of the heat sector, the PBL has developed a model. This model is called the Vesta/MAIS model. The Province of South Holland (PZH) on the other hand foresees a planned, central development of a large-scale connected main heat infrastructure. The Provinces have formal role of coordinating municipal heat plans. In South Holland, the PZH sees opportunities to realize a large district heating infrastructure, partly fed with residual heat from the Rotterdam Harbour. To realize this infrastructure the PZH collaborates with Havenbedrijf Rotterdam, Gasunie, Eneco and Warmtebedrijf Rotterdam.

Table 1 Overview differences between approaches

	The PBL	The PZH
Driving force	Market	Plan
Scope	Municipality	Province
Objective for district heating	Develop district heating as a means to minimize energy costs for a set of consumers at neighbourhood level.	Develop district heating as a means facilitate the complete phase-out of natural gas. Adopt a utility maximizing perspective at the level of the whole province.
Role of municipality	Director of the transition facilitates local development of district heating systems in collaboration with local market parties.	Organizes local demand in collaboration with Province
Role of Province	Coordinates between municipal plans	Organizes regional demand, supply and infrastructure in collaboration with municipalities and market parties
Result	Distributed small-scale district heating infrastructures	Large main district heating infrastructure

These two approaches differ in terms of driving force, scope, the role of the municipality and the province and the expected design of district heating infrastructure (table 1). In addition, these two approaches may have different implications for the public-acceptance of the transition, and the achievement of national and international CO_2 abatement goals. However, these two approaches were not yet compared. As such, there is no insight in the effect of these two approaches on these local and national transition-objectives for municipalities. Moreover, if we link the two approaches to the framework on energy transitions, developed by Cherp et al (2018), we see that the PBL adopts a more techno-economic perspective, where development of infrastructures is the result of (gradual) changes in resources, natural life cycles of assets, population growth and economic growth. On the other hand, the PZH adopts a more political perspective, where goals, interests, institutions and capabilities shape change.

1.1.5 PUBLIC ACCEPTANCE OF THE HEAT TRANSITION

As discussed briefly in 1.1.3, the phase-out of natural gas has a very strong public component. There is currently no legal framework in place that enforces the phase-out of natural gas in the existing built environment. Residents have the final say; individual homeowners and majority tenant groups have the mandate to realize or block the transition at building-level. Tenants can support or block the phase-out of natural gas through majority voting in consultation evenings of the housing association and individual homeowners decide about their own investments. Therefore, in this transition process, municipalities are very dependent on the public acceptance of their transition approach. Moreover, for the realization of this approach, municipalities are dependent on the actions of companies, industry, housing associations and residents towards the phase-out of natural gas.

The importance of realizing public support for this transition and incorporating approaches for realizing public support in municipal policy-making about the transition is evident, yet not easily achieved. Orienting unstructured interviews with policy makers and communication professionals in Dutch municipalities (Amsterdam, Leiden and Rotterdam) indicate that they find it difficult to initiate and organize communication with regard to the decision-making processes about the implementation of district heating networks. The following reasons were mentioned:

- Insecurities in the political process block early and consistent communication.
- Policy development and communication are two separate internal processes.
- Municipalities do not know what information residents consider relevant.
- Municipalities struggle with their own role in the decision-making and communication about the phase-out of gas towards residents.
- Municipalities struggle with their own role in the transition. On the one hand municipalities have a societal role in which they want to steer towards a social and economic ‘’optimal’’ choice, on the other hand these municipalities have no legal power to steer the phase-out of natural gas.
- Municipalities struggle with reaching residents beyond their normal audience. There is a “standard” audience, which is not a fair reflection of the diversity of the residents in the municipality.
- Municipalities want to have a complete overview of all the information before they start communicating; they want to be able to answer all the questions residents may have.

- Municipalities have Limited resources and value larger overarching socio-economic problems over the phase-out of natural gas.

The approach of the PBL and the approach of the PZH result in several different transition paths, which can be (partially) steered by local and regional governments, but which also strongly depend on public support, economic development and other external factors. For a transition to occur, the dominant technology, natural gas, needs to lose its self-evidence. Destabilizing the current regime makes the system receptive to several (more sustainable) pathways of regime development. In this period of crisis, the system is likely to develop towards the preferential pathway of the dominant actor coalition (Arentsen, 2002). Residents are an important heterogeneous group of stakeholders, which can organize themselves and become a part of this dominant actor coalition. There are several examples in The Netherlands where residents organized themselves to achieve common goals with regard to the district heating system. These goals can be to achieve (Schwencke, 2016) and to block (Planbureau voor de Leefomgeving, 2017a) the development of district heating networks. Besides this, residents can be passive, which can lead to an impasse. The heat transition provides no financial incentives for residents to uptake a role in the change; and preceding research has found that a sense of urgency is often lacking and that people do not project the phase-out of natural gas on themselves (HIER Klimaatbureau, 2016, 2017a).

Moreover, the success of the transition approach currently does not only depend on public acceptance, it also depends on public action. While sequence of acceptance and action is not a given. Stimulating private investments in residential energy systems and sustainable home improvements is traditionally difficult (Wilson & Dowlatabadi, 2007). There is a gap between technological and economic potential, and actual market behaviour (Brown et al (1998). Moreover, residents do not necessarily make reason based-decisions; they can also make intuition-based decisions, which are stooled on perceptions and ways of reasoning that the municipality may not be able to foresee.

It is important to understand what drives public acceptability in sustainable energy transitions, like the phase-out of natural gas, as it will be hampered without public support (Perlaviciute & Steg, 2014). Especially because the mandate in the heat transition lies with the residents. However, it is currently unclear how municipalities can accomplish this support. Rotmans et al (2001) suggest that a process of collective learning and decision-making can realize public-support in energy transition. Still, they do not further elaborate on this. In addition, recent research agendas show that realizing public support and public action is still a great barrier for energy transitions (PERSON, 2016; Platform for Energy Research in the Socio-economic Nexus (PERSON), 2014). There is therefore a need to develop a better understanding of the options to create public support for this heat transition.

1.1.6 MODEL-DRIVEN POLICY ADVICE

The Dutch association of Municipalities, the VNG, advices municipalities to start exploring their heat policy-options based on so-called energy atlases (VNG, 2018). *"De vraag bij aanwezigen is niet of er een Energieatlas moet komen maar hoe deze er zo snel mogelijk kan komen."* (VNG, 2018). Over the past year, it became clear that indeed for many municipalities, the first step in formulating their transition plans is gathering expert advice, in the form of these atlases, on the technical and economic feasibility of alternatives for natural gas. This advice is commonly based on tools that evaluate which alternative for natural gas would fit in which district, based on the technical characteristics of the build environment and financial trade-offs (CEGOIA, Pico, Vesta/MAIS, ETM, Warmte Transitie Atlas etc.). However, where several organizations have mapped the advantages and options of these models (Netbeheer nederland, 2017; VNG, 2018), there is limited insight in the assumptions underlying these models and their respective limitations and disadvantages. An important open-source model, which functions as the basis of CEGOIA and Pico, is the Vesta/MAIS model, which is developed by Netherlands Environmental Assesment Agency (PBL). This model was originally designed to test and evaluate the effects of national policy measures on the development of the heat sector. However, the model currently also functions, directly (in Utrecht and Dordrecht) and indirectly (via CEGOIA and PICO), also as an important source for municipal policymaking.

1.1.7 KNOWLEDGE GAP AND PROBLEM STATEMENT

The introduction reveals two policy objectives for municipal heat plans. These policy objectives are: 1) cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050, and 2) public acceptance and large-scale public uptake of the phase-out of natural gas. Municipalities need to take the social, economic and technical aspects of energy systems into account when selecting an approach for the phase-out of natural gas and formulating policy for the heat transition. They need to find a balance between serving the local needs with regard to the transition on one hand in order to achieve public support for the transition, and contributing to national and European goals for CO_2 emission reduction on the other hand. While these two objectives do not necessarily collide, they also do not necessarily harmonize. Currently, it is unclear how municipalities can write effective policy for the heat transition that is sensitive to both these local and national objectives, as municipalities have limited knowledge on their policy options and the effect of their policy on these objectives. Municipalities need additional insights in the two overarching approaches for the development of district heating in South Holland with regard to both policy objectives. The following information is lacking:

- Effects of approaches on cost-effectiveness of CO_2 abatement
- Effect of approaches on realizing 85-90% reduction of the 1990 emission levels in 2050
- Processes to realize public acceptance for the heat transition

Moreover, it is unclear how the outcome of the tools that are currently being used to develop initial policy plans for the phase-out of natural gas, is shaped by underlying assumptions and model limitations. It is unclear what the effects of this data-driven policy advice is on the achievement of the aforementioned local and national policy goals. The first is particularly important in South Holland, where the Province of South Holland adopts a radically different approach for the development of district heating infrastructure than the PBL has implemented in its Vesta/MAIS model.

1.2 RESEARCH OBJECTIVE

The research objective is to identify the advantages and disadvantages the approach of the PBL and the approach of the PZH for realizing district heating with respect to cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050, and to determine how municipalities can develop effective decision-and-communication processes in the heat transition at a municipal level, in order to achieve public acceptance and large-scale public uptake of the phase-out of natural gas.

1.2.1 SOCIETAL RELEVANCE

ENVIRONMENTAL PLANS

The underlying societal aim is to support municipalities in formulating transition policy. By 2021, all Dutch municipalities need to have formulated heat policy for their environmental plans. However, because of the early stage of the transition and the existence of radically approaches for the development of district heating infrastructure, it is unclear what types of trade-offs municipalities need to make in the formulation of their policy, with regard to the aforementioned policy goals. Additionally, it is unclear if current processes of knowledge development fit with the necessity of realizing public acceptance of the heat transition.

MODEL DRIVEN POLICY-ADVICE

Moreover, while municipalities are advised to develop their policy based on heat atlases (VNG, 2017), there is actually limited insight in the assumptions underlying these model and their resulting limitations. In a situation where the information-demand is high and experience is low, these models may have a large influence on the formulated policy. Especially in South Holland, where the approach of the PZH is radically different than the approach of the PBL, which is implemented in Vesta/MAIS and serves as an input for both national and local policy, this may be problematic. In this thesis we aim further elaborate on the differences between the two approaches and we aim to reflect on the position of the Vesta/MAIS model in the formulation of transition policy in South Holland, with the purpose of placing the results of this (and related) model(-s) into perspective.

1.2.2 SCIENTIFIC RELEVANCE

POSITION OF COMPLEX QUANTITATIVE MODELS IN POLICY-MAKING

This thesis will provide an example in how quantitative energy-transition models, which are always a narrow representation of reality, could shape Dutch heat transition-policy. This example will underpin the importance of human interpretation of the data results, based on critical evaluation of the data-inputs and model assumptions, which is necessary to value the model outcomes correctly. This is not a new finding. *"Models in science may be used for various purposes: organizing data, synthesizing information, and making predictions. However, the value of model predictions is undermined by their uncertainty, which arises primarily from the fact that our models of complex natural systems are always open. Models can never fully specify the systems that they describe, and therefore their predictions are always subject to uncertainties... this leads to a paradox: the more we strive for realism by incorporating as many as possible of the different processes and parameters that we believe to be operating in the system the more difficult it is for us to know if our test of the model are meaningful... scientists should eschew long-range deterministic predictions, which are likely to be erroneous and may damage the credibility of the communities that generate them."* (Oreskes, 2003, p. 13)

PUBLIC ACCEPTANCE OF ENERGY TRANSITIONS

Realizing public support for energy transitions is a complex topic, which is in need of better understanding (PERSON, 2016; Platform for Energy Research in the Socio-economic Nexus (PERSON), 2014). The research agenda of the Groningen University on the topic of the human dimensions of sustainable energy transitions explains this: *"we need to better understand how to improve decision-making, communication and procedural issues (on a local and national level) related to siting and design of installations.... The need for more research on the human dimensions of transitions to sustainable energy systems is widely advocated, and seems pivotal to address the key challenges we face in making a successful transition"* (Platform for Energy Research in the Socio-economic Nexus (PERSON), 2014).

According to PERSON, this human dimension of energy transitions consists of three elements. Firstly, the understanding of factors that encourage sustainable energy use by consumers. Secondly, the understanding of effectiveness of policy interventions that facilitate energy conservation and the transformation to renewable energy systems. Thirdly, the understanding of factors that predict public support and the acceptability of sustainable energy systems and policies. The third section of the research falls within this last category: the acceptability of sustainable energy systems and policies. It is important to understand what drives public acceptability in sustainable energy transitions, like the phase-out of natural gas, as it will be hampered without public support (Perlaviciute & Steg, 2014). Exploring Q-methodology as a research method to gather inputs for designing a communication-and-decision making process for the phase-out of natural gas, is a novel use of the research methodology. Moreover, it potentially contributes to our understanding of how to realize public support for energy transitions.

1.3 INTEGRATION

This research is conducted for the double degree in Complex Systems Engineering and Management, and Science Communication. The thesis consists of four sections: 1) problem description and thesis outline, 2) cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050, 3) public acceptance and the large-scale public uptake of the phase-out of natural gas, and 4) integration and policy advice.

Section 2 contains the research on:

- Effects of approaches on cost-effectiveness of CO_2 abatement
- Effect of approaches on realizing 85-90% reduction of the 1990 emission levels in 2050

This research is conducted for the master Complex Systems Engineering and Management.

Section 3 contains the research on:

- Method to investigate public acceptance for the heat transition

This research is conducted for the Science Communication. The introduction and integration of the two perspectives is for both masters.

Section 4 contains a reflection on the effect of the method for realizing public acceptance for the energy transition in current processes of knowledge development.

2.

RESEARCH APPROACH

In this research, the approach of the PBL and the approach of the PZH towards realizing district heating in South Holland are evaluated in the light of the cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. In section 2.1, we will discuss the research approach for the CoSEM part of the thesis. In Section 2.2, we will discuss the research approach for the SEC part of the thesis. In section 2.3, we will discuss how we will integrate both parts. Finally, section 2.4 contains an overview of the thesis outline.

2.1 SECTION 2: COST EFFECTIVE CO_2 ABATEMENT THROUGH DISTRICT HEATING

The overarching research objective is to identify the advantages and disadvantages the approach of the PBL and the approach of the PZH for realizing district heating with respect to cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050, and to determine how municipalities can develop effective decision-and-communication processes in the heat transition at a municipal level, in order to achieve public acceptance and large-scale public uptake of the phase-out of natural gas. Section two in this thesis focusses on the objective of cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050.

This policy goal is two folded. Firstly, it contains the goal of cost-effective CO_2 abatement. Which indicates, that when there are alternatives for fossil-based energy sources, policy should focus on selecting the alternative that has the lowest costs per ton CO_2 abatement. Secondly, it contains the goal of 85-90% of the 1990 emission levels in 2050. This indicates that policy should focus on selecting alternatives for fossil-based energy sources, which accelerate or at least do not impede the transition to a low-carbon economy as a whole. For district heating development, this means that it is necessary to think in terms of cost-effectiveness of network and resource development and the effects of remaining CO_2 emissions, but also in terms of transition-scale and co-existence of alternatives for natural gas (with currently higher costs, but also higher CO_2 abatement potential).

To compare the two approaches, we will analyse how they differ in terms of their theoretical perspective, their main concepts, the methods deployed to develop scenarios, the scenarios themselves and the way these scenarios contribute to realising the aforementioned policy targets (figure 2).

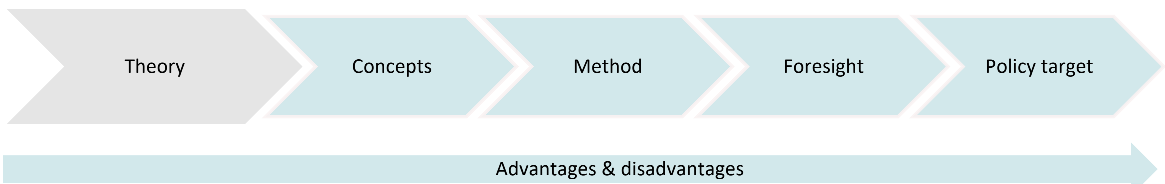


Figure 2 Overview of steps in comparison of approaches

The focus of the thesis lies on the methods, scenarios and policy targets as it is necessary to scope and most information available on the approaches is related to these three aspects. The methods will be described in terms of data sources, tools and assumptions, and actor coalitions. The scenarios will be described in terms of, consumers: type, market share and location, producers: type, market share and location and network design: routes and capacities. The evaluated policy targets are the costs of CO_2 abatement and the overall transition potential. Table 2 shows an overview of the comparison steps, the content of the comparison and the research method deployed. The table also shows how reflection on the research outcomes will result in the identification of advantages and disadvantages of the respective approaches.

Table 2 Overview of steps in comparison of approaches in relation to research methods

	Content	Method	Reflection
Theory	Link to theoretic framework on energy transitions	Brief literature review	Outside of scope: further research
Concept	Driving force, scope, main actor roles, market organization, growth pattern, resource strategy	Grey literature search	Advantages and disadvantages
Method	Tools, assumptions, processes	Expert consultation Model exploration	
Scenario	Demand, supply, infrastructure, market share	Expert consultation Model exploration	
Policy target	CO_2 emissions, overall investment costs, costs of heat supply	Dispatch model Cost model	

In 2.1.1-2.1.3, we will discuss the research questions, we will provide an overview of the research approach and we will discuss the selection of research methods. Section 2.4 contains an overview of the thesis.

2.1.1 RESEARCH QUESTIONS

The first part of this research focusses on the differences between the two approaches for realizing district-heating infrastructure with regard to their impact on realizing the European policy goals for the decarbonisation of the built environment and the resulting costs. The research objective is to identify relevant differences between the two regional transition approaches, with regard to the implementation of district heating at a municipal level for realizing cost-efficient CO2 abatement. This leads to the following research questions:

What are relevant differences between the two regional transition approaches, with regard to the implementation of district heating at a municipal level for realizing cost-efficient CO_2 abatement?

1) What are the main conceptual differences between the approaches of the PBL and the PZH for the development of a province-wide district heating approach for South Holland?
2) What are the main differences between the methods the PBL and the PZH deploy to develop scenarios about the development of district heating systems in South Holland?
3) What are the expected system designs based on the approach of the PBL and the PZH for developing district heating in South Holland?
4) What are the differences between the system designs for district heating infrastructure in South Holland with regard to CO2 emissions, overall investment costs and costs of CO2 abatement?
5) What are the main uncertainties and risks with regard to the two approaches for developing district heating, for the development of district heating at a municipal level?

2.1.2 OVERVIEW RESEARCH APPROACH

Firstly, to identify the main conceptual differences between the approach of the PBL and the approach of the PZH a grey literature will be performed. This search will result in an overview of the main conceptual differences between the approaches. Secondly, to identify the main conceptual differences between methods the PBL and the PZH deploy to develop scenarios for the development of district heating infrastructure, the methods will be explored, using a grey literature search and expert consultation. This will result in a description of the two methods the PBL and the PZH use respectively to develop scenario for district heating in South Holland. Thirdly, to identify what system designs the two approaches could potentially lead to towards 2030, scenarios are made for both approaches. These scenarios will be based on same methods as the PZH and the PBL apply to develop their vision on district heating and they will be selected in consultation with the PBL and the PZH. Fourthly, these scenarios will be compared in terms of the marginal costs of heat production, expected heat production and consumption, network efficiency and CO_2 emissions. To make this comparison firstly, an economic dispatch model will be developed and secondly, an existing cost-model will be adapted to fit the level of detail of the scenarios. Throughout the process, we will critically reflect on the gathered data and information, to identify uncertainties and risks related to district heating development following the two approaches. The total of these research steps will provide insights in relevant advantages and disadvantages of the two regional transition approaches, with regard to the implementation of district heating at a municipal level.

Table 3 shows an overview of the research method used to answer each of the sub-questions. In addition, the table shows what the expected outcome of these research steps is.

Table 3 Overview research questions, methods and outcomes

	Research question	Method	Outcome
1	What are the main conceptual differences between the approaches of the PBL and the PZH for the development of a province-wide district heating approach for South Holland?	Grey literature search	Overview of conceptual differences approaches.
2	What are the main differences between the methods the PBL and the PZH deploy to develop scenarios about the development of district heating systems in South Holland?	Expert consultation Model exploration	Overview of main differences between methods the PBL and the PZH deploy to build scenarios for their approaches.
3	What are the expected system designs based on the two approaches for developing district heating in South Holland?	Expert consultation Model exploration	Scenarios for DH development based on these approaches.
4	What are the differences between the system designs for district heating infrastructure in South Holland with regard to CO2 emissions, overall investment costs and costs of CO2 abatement?	Dispatch model Cost model	Comparison of CO_2 emissions, overall investment costs and costs of heat supply of scenarios.
5	What are the main uncertainties and risks with regard to the two approaches for developing district heating, for the development of district heating at a municipal level?	Interpretation	Overview of main uncertainties and risks related to the approaches.

2.1.3 Method selection

Through the outcomes of research question 1, 2 and 3, we build an understanding of the two approaches: the conceptual differences, the methodological differences and the differences in the expected transition-outcome. These approaches are relatively unexplored, as the transition of the low-temperature heating system in South Holland is still in a very early phase. Therefore, for research question 1, 2 and 3 we will evaluate the existing literature and models available that support or explain the approaches of the PZH and the PBL. Moreover, to acquire additional information where necessary, we will consult experts from the PZH and the PBL respectively.

To answer research question four, it is necessary to develop a new model or utilize an existing model, which can calculate CO_2 emissions, overall investment costs and costs of heat supply of different district heating system designs. This model should at least be able to calculate design-specific investment costs and match the supply and demand of heat over time, given constraints on demand, production, transport and storage. The selection of a model for the comparison of the CO_2 emissions, overall investment costs and costs of heat supply of the scenarios is discussed in section 2.1.4. To answer research question five, we will reflect on the research outcomes.

2.1.4 Model selection

To determine what type of model could be applied, we will first perform a literature review, to identify what types of model are common for simulating district heating system operation and what type of model could fit this modelling objective. Secondly, we will look at the heat-transition models currently available in the Netherland to see if an existing model can be used to perform this step in the research.

Literature review district heating models

A literature review shows that there are in general four types of models of district heating systems. These models are simplified representations of district heating networks, each with a specific focus and purpose. Pavi et al. (2017) explain that district heating networks are often simplified because it is a computationally difficult task to optimize design and operation of a district heating system, due to a large number of parameters that need to be considered and calculated. Moreover, there is a need for long optimization horizons of at least one year, in order to capture seasonal, and a time step of 1 h or less, to capture intraday variations (Pavi, Novosel, Puk, & Dui, 2017, p. 1) which adds to the computational demands. Vesterlund et al. (2016) describe three general approaches for modelling a heat network for the optimization of planning and operation of a district heating system:

1) Network as a black-box
The network is represented as a black box. This type of model can for example be used when the focus lies on the model of the heat plant or the integration between the electricity and heat market. These model usually only contain one or two heat sources. Heat consumption is modelled as a sink.
2) Detailed small-scale networks
The model of the network is technically detailed. These models can be used for design analysis and optimization, operational optimization or the evaluation of the effect of adding a heat source on the physical behaviour of the network. These models often represent small and simple district heating networks.
3) Simple network planning
The model of the network is the result of the optimization. The model optimizes the topology and design of the network. The focus does not lie on the detailed simulation of the network behaviour. Optimizing the planning of the network can be done based on economic, technical and sustainability objectives. However, design options are often pre-defined and the studies only describe small networks.

A 4^{th} category of district heating models is described by Benonysson et al (1995). These are economic dispatch models for operational optimization of district heating systems.

4) Economic dispatch
In an economic dispatch model, the objective function is minimized. The objective function consists of the marginal costs for production, transport and storage, for each time step.

An economic dispatch model combines information about the technical design with information about the costs of the system. An economic dispatch model of a district heating system, provides a fast and easy evaluation method and gives useful results before the detailed project planning of DH system investment (Pusat & Erdem, 2014).

An economic dispatch model does not calculate the investment costs in district heating infrastructure. However, to calculate these costs, the logic for the investment costs and fixed costs for district heating systems, as implemented in the Vesta/MAIS model will be evaluated in the context of this research, and adapted where necessary. Then the model is then implemented in excel. This process is further described in chapter 4.

The comparison of the identified system designs thus consists of two steps. Firstly, for all system designs the initial investment costs and maintenance costs will be calculated. Secondly, the network operation will be simulated, to evaluate the marginal costs of heat production, expected heat production and consumption, network efficiency and CO_2 emissions.

MODEL REQUIREMENTS DISPATCH MODEL

The literature review shows that based on the available data and the purpose of the study, it is best develop an economic dispatch model. Under the assumption of a perfect market, an economic-dispatch model can represent district heating system operation. An economic dispatch model of a district heating system can provide insights in the marginal costs of heat production, the utilization of heat sources, storages and infrastructure, and basic system operation (incl.: heat losses and CO_2 emissions). A dispatch model of a district heating system should contain the following elements (Pusat & Erdem, 2014; Wouters, Fraga, & James, 2015):

1) Area specific climatological data
2) Technical specifications: energy infrastructure, generation, storage and supply technologies
3) Cost data: capital costs, operation and maintenance costs and utility energy tariffs.
4) Country specific regulations: regulation affecting the costs and/or availability of heat
5) Spatial distribution of hourly average energy demands

Moreover, to fit within the context of the transition in South Holland, the dispatch decision should be based on (Warmte Koude Zuid-Holland, Alliander, Berenschot, Agro Energy, E.on, Prominent, Provincie Zuid-Holland, LTO Glaskracht, 2015):

- Price-differentiation between location, based on transport constraints and/or transport losses.
- Transparency on the CO_2 content of heat, and potentially inclusion of the CO_2 emissions in the dispatch decision.

Because of seasonal and hourly fluctuations in the heat demand, the appropriate time-step to determine the dispatch schedule of the heat sources is an hour and the minimum time horizon is a year. To include heat storage, the model should be able to optimize the dispatch-decision over a number of time-steps.

The optimization objective is to satisfy the heat demand for each consumer with the lowest marginal cost plants, given the physical constraints on demand, production, transport and storage and economic data on the marginal costs of heat production, the costs of heat losses and the costs of CO_2 emissions. Moreover, the model output is the optimal hourly dispatch schedule for all available heat sources in South Holland, given the model constraints.

DISCUSSION AVAILABLE MODELS IN THE NETHERLANDS

In the Netherlands, several models for the evaluation of district heating are developed: CHESS, VESTA/MAIS, CEGOIA, DIDO, DSSM, energietransitiemodel, ES-IT, Gebiedsmodel, Moter, OPERA, PICO, POWERFYS, Transoform, Warmtevraagprofielen, Win3ed and Woonconnect (Netbeheer nederland, 2017). The Vesta/MAIS model calculates the optimal choice for a heating system on neighbourhood level. CHESS can be used to optimize a network design for district heating network performance, toward different performance indicators. In addition, the NEN7025 norm calculates the performance of a district heating system in terms of CO_2 emissions. CEGOIA, DIDO, DSSM, energietransitiemodel, ES-IT, Gebiedsmodel, Moter, OPERA, PICO, POWERFYS, Transoform, Warmtevraagprofielen, Win3ed and Woonconnect, have a different model focus that lies further outside the scope of the research. The Vesta/MAIS model, CHESS and NEN7025 are discussed more in-depth below.

VESTA/MAIS

Vesta/MAIS is a GIS model, developed by The Netherlands Environmental Assesment Agency(The PBL) for evaluating the development of the energy demand of the built environment and its energy systems. It is the only model combining policy measures and related expectations about the development of the demand and supply, with cost-economic trade-offs about the choice for optimal system design. It uses a rule-based optimization to establish the cost-optimal choice for a heating system at neighbourhood level. However, Vesta/MAIS only evaluates optimal choices at the level of a neighbourhood. It is unable to evaluate which system designs are optimal when multiple neighbourhoods could be connected. The model does not take economies of scale into consideration and cannot calculate district heating networks more complex than networks based on a single source with multiple consumers. This is an important limitation as the model is therefore not suitable to evaluate the approach of the PZH.

CHESS

Is a sophisticated tool for optimization of the design of district heating systems, towards key performance indicators, such as CO_2 emissions, investment costs and operational costs, based on a method of distributed control. The tool is developed by TNO. This tool requires detailed system designs at the level of a municipality or a region, about the demand, supply and infrastructural design. The available data is insufficient to evaluate the two approaches for developing district heating using this tool.

NEN7025

The NEN7025 norm uses annual demand figures and thermal capacities to estimate the annual heat production per heat production plant. The norm disregards heat infrastructure. As such, it neglects temporal and spatial mismatches between supply and demand due to production constraints (ramping constraint, maintenance etc.), consumption patterns (weather conditions, behaviour, building type, hot water demands), network constraints (max. capacity, losses, min. flow) and the network behaviour (temperature losses, pressure changes). The calculation method disregards heat storage, which can reduce the use of peak load plants.

More specifically, to estimate the annual production per plant, the method assumes that 26% of the heat demand is supplied by a peak load plant. The base load plants supply the other 74% of the heat demand. The production of each base-load plant depends on its available thermal capacity and its status as ‘’preferred production plant’’. Preferred production plants are geothermal heat sources and solar boilers. Thermal losses within the network are represented as extra demand. Moreover, the NEN norm contains pre-defined values for pump-energy per MJ supplied heat. The allocation of the costs of pump-energy is again based on the installed thermal capacity of each plant. As such, the costs of pump energy and heat losses are allocated over the heat producers, independent of the time of production. Moreover, the method calculates CO_2 emissions independent of the actual quantity of heat production per plant.

The calculation method described in the NEN7025 norm strongly simplifies the actual dispatch of plants on a district heating network. Especially when the system becomes more complex i.e.: multiple plants complex network design etc. This method may be too general to calculate the CO_2 emissions from district heating, as the trade-offs between which plans will produce heat wills include more variables. Comparing different system designs using the calculation method from the NEN 7025 norm would result in a dispatch decision and corresponding CO_2 emission numbers, which strongly simplify system operation and does not reflect the differences in network designs in the two visions. The NEN7125 norm does not take heat infrastructure limitations, ramping constraints and storage into consideration when calculating the annual production of heat. Therefore, the norm is not suitable to compare the energy system designs resulting from the two approaches for realizing district heating in South Holland.

CONCLUSION

None of these models and norms provides insight in the performance of a district heating network based on the system design and the related economic dispatch decision, based on the high-level available data. It is therefore necessary to develop a model that can do this.

TOOL SELECTION

Determination of the economic dispatch of different heat producing units, sometimes considering a heat storage can be done through linear programming, when the supply temperatures are considered constant or predetermined (Benonysson, Bohm, & Ravn, 1995). Mixed Integer Linear Programming (MILP) is a common method for operational optimization of multi energy systems (Mancarella, 2014) and urban energy systems (Keirstead et al., 2012; Manfren, Caputo, & Costa, 2011). A Mixed Integer Linear Program (MILP) consists of variables, linear constraints on these variables, and an objective function, which is to be maximised or minimised under these constraints. In a MILP optimization, only some of the unknown variables are required to be integers, the other variables can vary within a range. A MILP solver can define the optimization problem as a convex problem, guaranteeing an optimal solution. A MILP model can include a linear approximation of; the physical network behaviour, technical specifications, and costs data. Moreover, spatial characteristics of the district heating system can be included. And (monetary) policy measures can be included.

Linear programming as a method is not suitable because the optimization problem contains integers (on/off – decisions for heat production plants). Non-linear programming should be applied when non-linearity on the objective functions or in the constrains is crucial for representing the optimization problem properly and at this point there is no reason to believe non-linearity is crucial. Multiple goal optimization would be an appropriate method for optimizing the dispatch of plants on a DH network when for example CO_2 abatement would be a goal. However, with the EU-ETS, the external effects of CO_2 emissions are priced and the CO_2 price can be included in a least-cost optimization. Given that the CO_2 price accurately reflects the value of CO_2 emissions, multiple goal optimization is not necessary. Therefore, MILP is a suitable method to develop a techno-economic model for the energy system designs resulting from the two approaches for developing district heating in South Holland.

SOFTWARE DESCRIPTION

Linny-r is dedicated software tool for modelling and optimizing industrial processes. Moreover, the time-horizon in Linny-r approximates a rolling time horizon. When the optimization period is 1 time step and the look-ahead is 6 time steps, the solver optimizes over 7 time steps, while only forwarding the time with 1 time step. As such, the software can also "optimize" the use of heat storage.

A Linny-r model consists of products and processes. Products can be sources, sinks, storages or junctions. Products can have a lower and an upper bound, indicating a minimum or maximum value for each time step. Moreover, products can have a price, which can vary per time step or remain constant. When a product is modelled as a storage, a product can have an owner, an initial level and a fee for storage per time step. Processes connect products. Processes can have an owner. Processes can have a single direction or can be bi-directional. Processes can have an upper and lower bound and these bounds can depend on the previous time step, the value at t=1, other product stocks and other processes. Processes can shut down when the lower bound is not met. Besides this, start-up costs for a process can be included. Processes can have variable costs depending on the flow through the process. Finally, processes can process multiple products; they can have multiple products flowing in and out. The ratio between the products in and out is constant.

ADVANTAGES

Linny-r is a dedicated software tool and is easy to use. The data requirements of the tool fit largely with the available data for both approaches. Linny-r can calculate an optimal dispatch for the right time-horizon and time step, given all modelling-requirements as described under *method selection*.

DISADVANTAGES

The Linny-r does not optimize the capacity of the different system components. It only gives signals when the constraints are too tight to solve the optimization problem. Optimization of capacities of system components needs to occur outside of the model. Besides this, the software requires simplifications of the thermodynamics and flow dynamics. In addition, the time-delay between demand signals and supply could not be modelled. The effects of these simplifications on the dispatch decision are unknown. Moreover, the Linny-r model only evaluates the feasibility of the design choices for the district heating system, but does not optimize them. Therefore, the system designs need to be checked for feasibility separately.

In addition, the Linny-r model does not calculate investment costs and fixed costs for network operation. Calculating investment costs and fixed costs needs to be done in a separate (excel-)model. And, Linny-r is not user-friendly with regard to data interpretation and scenario analysis. Data needs to be exported manually to excel before proper evaluation can take place. In addition, scenarios need to be run manually. Values need to be adjusted one-by-one by clicking through the model.

2.2 SECTION 3: PUBLIC SUPPORT FOR THE HEAT TRANSITION

As described in section 2.1, the second section of this thesis will focus on comparing the approach of the PBL and the approach of the PZH for developing district heating in relation to cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. This results in an overview of the key-differences between the approaches, and a quantitative comparison of potential costs and benefits and the identification of some key uncertainties. One of the main identified uncertainties for both approaches is that of public acceptance of the transition, and the dependence of the realization of the transition on the willingness and ability of individual residents to participate in the transition. Therefore, the third section of this thesis will focus on the realization of public acceptance and large-scale public uptake of the phase-out of natural gas. However, researching public acceptance is not straightforward. There is a need to improve the understanding of factors that predict public support and the acceptability of sustainable energy systems and policies (PERSON, 2016).

Therefore, in the third section of the thesis, we first aim to find a method through which we can get an understanding of the public acceptance of the approaches for developing district heating. This third part of the research adopts transition management as a theoretical framework. Transition management is based on the idea that sustainable development requires changes in socio-technical systems and wider societal change – in beliefs, values and governance that co-evolve with technology changes. From a transition-management perspective, participatory decision-making and collective learning and education are two methods through which public support for energy transitions can be realized (Rotmans, Kemp, & van Asselt, 2001).

This means that from this perspective, to achieve public acceptance and facilitate public action for the phase-out of natural gas, it is necessary to organize a process in which relevant stakeholders, such as the municipality, residents and relevant commercial parties interact and collaborate to develop a shared vision of the transition. Based on Wilson and Dowlatabadi's (2007) literature review and analysis of decision making in residential energy use, we assume that there are multiple resident- perspectives on the phase-out of natural gas. Moreover, based on Wenger (2000) and Butler et al (2015) description of Communities of practice, we assume that it is necessary that the selected approach for communication-and-decision-making about the phase-out of natural gas fits with the residents needs with regard to the organization and the content of the process of the phase-out. Therefore, the proposed method to identify resident perspectives on the phase-out of natural gas, should allow for identifying multiple subjective perspectives on the communication-and-decision-making process about the phase-out of natural gas.

Secondly, we will apply and test this method in a case study and discuss the results in a focus group with the respective policy-makers in the municipality in which the case study has taken place. This should provide some initial insights in the suitability of the method for the purpose. Thirdly, the overarching aim is to identify the advantages and disadvantages of both approaches with regard to public acceptance of the transition towards a carbon-free heating in the built environment, in order to support municipalities in developing local heat plans. Due to limited time, this second aim cannot be fully achieved. However, at the end of this third section of the thesis, we will perform a brief analysis on the potential impact of the method, when widely applied, on the development of municipal heat plans. In section 2.2.1-2.2.3, we will discuss the research questions, the research approach and the research methods.

2.2.1 RESEARCH QUESTIONS

The second part of this research focusses on designing effective decision-and-communication processes in the heat transition at a municipal level for establishing public acceptance of the heat transition. The research objective is to determine how municipalities can develop effective decision-and-communication processes in the heat transition at a municipal level, in order to achieve public acceptance and large-scale public uptake of the phase-out of natural gas. This leads to the following research questions:

How can municipalities gain insight in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level?

1) How can the design of decision-and-communication processes contribute to the public acceptance of the heat transition?
2) How can municipalities identify the perspectives of residents on the process of the phase-out of natural gas?
3) What is the relevance of the perspectives of residents on the process of the phase-out of natural gas for designing effective communication-and-decision making processes in the heat transition?

2.2.2 OVERVIEW RESEARCH APPROACH

Table 4 shows an overview of the research questions, the research methods and the outcome of each of the steps in the research.

Table 4 Overview research questions, methods and outcomes

	Research question	Method	Outcome
1	How can the design of decision-and-communication processes contribute to the public acceptance of the heat transition?	Structured literature review	Conceptual model public support in the heat transition.
2	How can municipalities identify the perspectives of residents on the process of the phase-out of natural gas?	Q- methodology	Example of q-study: from discourse analysis to perspectives on the phase-out of natural gas.
3	What is the relevance of the perspectives of residents on the process of the phase-out of natural gas for designing effective communication-and-decision making processes in the heat transition?	Focus group	Insight in relevance of research approach and potential results for municipality.

2.2.3 METHOD SELECTION

In this section, we will discuss the method selection. Firstly, we will discuss the choice for a structured literature review for developing a theoretic framework. Secondly, we will discuss the use of Q-methodology for researching perspectives of residents on the municipal governance of the implementation of district heating networks in their own neighbourhood. Thirdly, we will discuss the use of a focus group to evaluate the relevance of the identified perspectives and the method deployed.

STRUCTURED LITERATURE REVIEW

A structured literature review is a method through which relevant literature can be mapped rigorously and systematically. The advantage of a structured literature review over a traditional literature review is that a structured literature review is transparent and reproducible. Moreover, a structured literature review it is very explicit. It is very clear which concepts the researcher has considered, and which the researcher has left out. Downsides of a structured literature review are that the outcome strongly depends on the problem definition and related word-map of the researcher. In that sense, a structured literature review is less dynamic than an unstructured review. However, as the understanding of the topic grows, the problem definition and related word-map can also be revised. Through one or more iterations on the search terms, initial limitations of the review can be overcome.

For this research, a structured literature review is selected because of its transparency. The research objective is to develop a method through which municipalities could gain insights in the perspectives of residents on the process of the heat transition at a municipal level. However, the period for the research is limited and it is therefore not possible to thoroughly test and evaluate the conceptual framework. Using a structured literature review as the basis of the framework however does makes it clear from what type of research the framework was derived, and potentially what additional or new literature could further improve the framework.

Q-METHODOLOGY

To determine how municipalities can identify perspectives of residents on the municipal governance of the implementation of district heating networks in their own neighbourhood, we have evaluated several research methods for subjectivity. Q-methodology is selected as the research method. Other research methods for subjectivity include using Likert Scale or (structured) interviews to evaluate statements. These two methods are less suitable for the purpose of this research. The Likert scale forces respondents to evaluate each statement separately, where Q-methodology forces the respondents to evaluate the statements in relation to each other. This difference is important when you want to force respondents to make trade-offs about what they find truly important or unimportant. Interviews miss the quantitative aspects of Q-methodology that allow the researcher to identify similarities between the perspectives. Moreover, interviews do not force respondents to make relative trade-offs between different process-factors in the same way Q-methodology does.

Q-methodology employs a by-person factor analysis to identify groups of participants who make sense of a pool of items in comparable ways (Watts & Stenner, 2005). The method is designed to research people's subjectivity with regard to a subject. Respondents are asked to structure a set of statements following a pre-determined procedure. While performing the sorting process, respondents are asked to think aloud. The ordering of the statements is analysed through factor analysis and factor-rotation. The method provide insights in the overlap of the ordering of the statements by the respondents. From these overlaps, subjective perspectives can be identified. These perspectives can be supported and checked with the gathered qualitative data.

Q Methodology is a research method that is especially suitable when it matters what the respondents think about the issue at hand. The revelation of the viewpoints should make a difference to the situation that is researched. In the case of the phase-out of natural gas, the viewpoints of residents on the process of the phase-out of natural gas can support municipalities in designing a process that is sensitive to the interests and attitudes of residents with regard to this transition. In addition, the outcomes of the Q-study can potentially support municipalities in selecting an approach for the development of district heating networks, as the different viewpoints that are identified through Q, can support in explaining what the risks and opportunities are for different municipal approaches towards the local phase-out of natural gas.

DISADVANTAGES OF Q

The outcomes of Q-methodological research cannot be extrapolated over time as individuals can change their minds. *"Q methodology makes no claim to have identified viewpoints that are consistent within individuals across time [as this would] impose a priori counterintuitive assumption that a given participant is capable of expressing only one coherent viewpoint on an issue. (…) Whilst this leaves individual exemplars free to „change their minds", we might nonetheless expect the emergent manifold of shared viewpoints to show a degree of consistency over time"* (Watts & Stenner, 2005, p. 86). This is an important limitation. Especially because the public-debate on the transition of the phase-out of natural gas is ongoing and people are becoming increasingly aware of the transition (HIER Klimaatbureau, 2016, 2017a). This indicates that perspectives may change over time because of changing awareness and a changing context. Therefore, it may be necessary to evaluate the validity of the perspectives over time.

Besides this, the outcome of the research says nothing about the percentage of a population that adheres to the perspective: *"the results are the distinct subjectivities about a topic that are operant, not the percentage of the sample (or the general population) that adheres to any of them"* (Van Exel and de Graaf, 2005, p.3). To determine the percentage of a population that adheres to a perspective, for example additional questionnaires can be performed. Alternatively, the researcher can try to identify common denotes between the respondents that are related to a perspective. In this thesis, we will look at socio-economic characteristics of the respondents, their awareness of the transition and their preceding actions for sustainable home-improvements, to see if we can find such common denotes.

FOCUS GROUP

A focus group is a qualitative research method, used to investigate thoughts, ideas, motives and interests with regard to a predetermined topic. In the context of this research, the focus group is used to check the internal consistency of the perspectives and to explore the relevance of the identified perspectives for the municipality in designing a communication-and-decision making process. A focus group allows for engaging in a structured and constructive discussion, in which the discussion leader can steer the discussion in such a way that participants can be equally heard. A focus group is selected as a research method because this allows for participants from both a policy and a communication background to interact on the results of the q-study. As the identified perspectives cover communication-and-decision making processes, it is interesting to see how officials from both the policy-department and the communication-department of the municipality evaluate the perspectives, and where they may agree or disagree.

2.3 SECTION 4: INTEGRATION AND FINAL RECOMMENDATIONS

In this section, we will reflect on the research outcome of section 2 and 3 of the thesis and we will discuss the potential implications of the research for municipal policy making in the heat transition in South Holland.

2.4 THESIS OUTLINE

Table 5 shows an overview of the thesis, including research questions and methods per chapter.

Table 5 Overview steps in research and chapters

Chapter	Research question		Method	Outcome
Section 1				
1		Introduction and problem description		
2		Research approach		
Section 2				
3	1.1	What are the main conceptual differences between the approaches of the PBL and the PZH for the development of a province-wide district heating approach for South Holland?	Grey literature search	Overview of conceptual differences approaches.
3	1.2	What are the main differences between the methods the PBL and the PZH deploy to develop scenarios about the development of district heating systems in South Holland?	Expert consultation Model exploration	Overview of main differences between methods the PBL and the PZH deploy to build scenarios for their approaches.
3	1.3	What are the expected system designs based on the two approaches for developing district heating in South Holland?	Expert consultation Model exploration	Scenarios for DH development based on these approaches.
4		Description economic dispatch model: MILP optimization model in Linny-R		
5		Description model investment costs and fixed costs district heating systems: adaptation of cost-calculation method in Vesta/MAIS, implemented in excel.		
6	1.4	What are the differences between the system designs for district heating infrastructure in South Holland with regard to CO2 emissions, overall investment costs and costs of CO2 abatement?	Dispatch model Cost model	Comparison of CO_2 emissions, overall investment costs and costs of heat supply of scenarios.
7	1.5	What are the main uncertainties and risks with regard to the two approaches for developing district heating, for the development of district heating at a municipal level?	Reflection	Overview of main uncertainties and risks related to the approaches.
8		Conclusion section 3		
Section 3				
9	2.1	What conceptual model can support designing a study into resident's perspectives on the phase-out of natural gas?	Structured literature review	Conceptual model public support in the heat transition.
10	2.2	How can the perspectives of residents on the municipal governance of the implementation of district heating networks in their own neighbourhood be identified?	Q- methodology	Example of q-study: from discourse analysis to perspectives on the phase-out of natural gas.
11	2.3	What is the relevance of identifying the perspective of residents on the municipal governance of the implementation of district heating networks for the organisation of governance between residents and municipalities?	Focus group	Insight in relevance of research approach and potential results for municipality.
12		Conclusion section 3		
Section 4				
13		Integration and final recommendations		

SECTION 2
COSEM RESEARCH

What are relevant differences between the two regional transition approaches, with regard to the implementation of district heating at a municipal level for realizing cost-efficient CO_2 abatement?

3.

COMPARISON OF TWO APPROACHES FOR REALIZING DISTRICT HEATING IN SOUTH HOLLAND

What are the main conceptual differences between the two approaches for the development of a province-wide district heating approach for South Holland?

What are the main differences between the methods the PBL and the PZH deploy to develop scenarios about the development of district heating systems in South Holland?

What are the expected system designs based on the approach of the PBL and the PZH for developing district heating in South Holland?

The aim of this chapter is to identify to what the main differences are between the two approaches for developing district heating in South Holland are, and how these differences affects the development of district heating in South Holland. In this chapter, we will look at the conceptual differences between the approaches, as they are described in grey-literature (3.1.1 and 3.2.1). Then we will look at the forecasting methods deployed by the PBL and the PZH to establish their ideas about the development of district heating (3.1.2 and 3.2.2). Finally, for each of the two approaches we will develop one or more scenarios for the development of district heating in South Holland (3.1.3, 3.2.3 and 3.2.4). These scenarios will be further explored using the models described in chapter 4 and 5. The chapter ends with a discussion of the differences between the two approaches (3.3).

In chapter 1, we have introduced that the PBL and the Province of South Holland differ in the approach for developing the heating distribution networks. Both approaches are aimed to contribute to the realization of the phase-out of natural gas, by 2050. However, the approaches differ strongly. In this chapter, the conceptual differences between the approaches are further explored. Moreover, for each of the approaches scenarios were made explore what the potential differences in transition-outcome will be. These scenarios are based on consultations with policy makers and model-experts of the PZH and the PBL respectively. These scenarios describe:

- percentage of consumers connected to DH per cluster and per consumer group in 2030

- available geothermal heat sources in each cluster in 2030
- the route and capacity of main district heating infrastructure

This information will be used as model inputs for the models described in chapter 4 and 5. Through the application of these models we will develop a better understanding of the total investment costs associated with these scenarios and their potential impact on the transition objective.

3.1 THE APPROACH OF THE PZH

In this section, we will discuss the approach of the PZH conceptually (3.1.1), we will discuss the methods the PZH deploys to develop and (quantitatively) support their approach (3.1.2) and we will present the main design uncertainties the PZH foresees with regard to the development of district heating infrastructure (3.1.3).

3.1.1 CONCEPTUAL DESCRIPTION APPROACH PZH

The Province of South Holland foresees a planned, central development of a large-scale connected heat infrastructure. The Province of South Holland is home to large industrial complexes in the Rotterdam Harbour, which are expected to continue to produce residual heat. To attain the intended sustainability targets the Province of South Holland wants to utilize this residual heat to its full potential and expects that this requires coordination of municipal heat plans and the development of a large interconnected and region-wide infrastructure. In the plan of the Province of South Holland, residual heat from the Rotterdam harbour will be used along with residual heat from waste incinerators, solar heat, geothermal heat and biomass-fired CHPs to create a large-scale connected heat infrastructure, that connects a diversity of heat sources to heat consumers via an open market (Province of South Holland, 2017a). In 2050, this system should supply approximately 50 PJ from sustainable heat sources to consumers within the whole of South Holland. Accounting for roughly 80% of the low-temperature heat demand in South Holland in 2050. In the approach of the Province of South Holland, by 2050 25% to 80% of the heat consumers will be connected to a district heating infrastructure. The remaining consumers will make-use of other alternatives for natural gas.

Important drivers for aiming for a central development of a large-scale connected heat infrastructure are expected economies of scale and the collective benefit of a more sustainable energy system (Province of South Holland, 2017b). The Province of South Holland currently emits eight Mton CO_2 equivalent for heating the built environment. Towards 2030, this should be reduced to approximately one Mton, and towards 2050, heating the built environment should be emission fee (Province of South Holland, 2017a). The expectation is that a large-scale connected heat infrastructure will achieve greater CO_2 emission reduction than small-scale distributed and disconnected district heating networks would, because a large-scale connected heat infrastructure, with multiple heat sources and an open market design can:

1. facilitate a wide employability of industrial waste heat, and renewable heat sources such as geothermal heat and biomass (Province of South Holland, 2017a);
2. overcome the location mismatch between the supply of residual heat and geothermal heat and the heat demand;
3. reduce the use of peak boilers for balancing supply and demand;
4. and, allow for market interventions which can steer towards the use of more sustainable heat sources.

In this planned development of infrastructure, initial investments in the primary heat infrastructure that facilitate network growth precede demand, and financial constructions are necessary that can support the initial over dimensioning of the heat infrastructure and mitigate investment risks.

The Province of South Holland has formulated this vision in collaboration with several public and private parties with expertise in the Dutch energy sector and district heating systems. In March 2017, Havenbedrijf Rotterdam, Gasunie, Provincie Zuid-Holland, Eneco and Warmtebedrijf Rotterdam signed a declaration of intent for the realization of this infrastructure and an independent network operator. This collaboration is called the Heat Alliance Zuid-Holland. This approach influences the spatial orderings, in terms of network structure, resources and connected consumers and different markets and institutions. Moreover, it influences local options and decision-processes.

Main expected disadvantages of this approach are that, *"'Grand designs' are always overtaken by unforeseen changes in the environment and because there are no mechanisms to guarantee the execution of such a plan."*(Planbureau voor de Leefomgeving, 2017b, p. 28). Additionally, *"Due to continuous uncertainties (financial and regulatory), no solid* *investment proposal can be made."* (Planbureau voor de Leefomgeving, 2017b, p. 67). In the next two sections, we will look into the effect of this approach on the spatial ordering.

3.1.2 FORECASTING METHOD AND SYSTEM DESIGNS

The Province of South Holland builds the vision on quantitative research into the development of demand for heat and potential heat sources, business cases for the various alternatives for the natural gas based heating system, case studies for different routes and options for the development of a large infrastructure, expert consultations and several larger organized administrative consultations. In consultation with a senior energy-policy advisor from the province of South Holland (27-09-2017, we have developed an understanding of the main options and uncertainties the institute sees for the development of district heating infrastructure.

DEMAND

In collaboration with the Province of South Holland, three alternatives for the market penetration rate of district heating networks given the central development of district heating networks were established. The market penetration rate describes the share of the heat demand that is located at consumers that are connected to a district heating network. These three alternatives are:

- 25% of the total heat demand in South Holland
- 50% of the total heat demand in South Holland
- 80% of the total heat demand in South Holland

For these alternatives, the assumption was made that the market penetration rate is equally distributed for all consumer groups, locations and types of buildings, building years etc.

SUPPLY

The Province of South Holland expects a high development of district heating networks towards 2030. Two scenarios for the development of district heating networks were established. These scenarios are shown in table 6. The scenarios are based on a capacity of 12,5 MW per geothermal well.

Table 6 Estimation installed capacity for geothermal wells in South Holland in MWth in 2030

	High (MW)	Low (MW)
Leiden	100.0	25.0
Lansingerland	150.0	75.0
Rotterdam North	0.0	0.0
Dordrecht	75.0	25.0
Rotterdam South	0.0	0.0
The Hague	275.0	162.5
Sum	**600.0**	**287.5**

SCENARIOS

Based on the scenario options for the demand and supply, there are six potential scenarios. In consultation with a senior energy-policy advisor from the province of South Holland (27-09-2017), four scenarios were selected for further research (table 7).

Table 7 Scenario selection

Name	Limited	Unforeseen	Abundance	Momentum
Total demand (MW/PJ)	794/25	1587/50	1587/50	2539/80
Share of demand connected to district heating	25%	50%	50%	80%
Development of geothermal heat	Low	Low	High	Low
Total supply (MW)	5921	7656	7968	12548

INFRASTRUCTURE

For the scenarios of the Province of South Holland, the route and capacity of the heat transport infrastructure is also plan-based, however it is necessary to fit these capacities with the gathered data on demand and supply. An under capacity indicates that heat transport capacity is too little to supply the base-load demand within a cluster. When there is an under capacity, the pipeline capacity needs to be increased to meet the minimum base-load. This process is further explained in appendix 5. Under capacities were adjusted to match the minimum demand criterion.

Overcapacities indicate that the planned transport capacities are larger than necessary to supply a minimum base-load. Overcapacities are not adjusted. Based on this analysis, the Momentum scenario is excluded. The necessary pipeline capacities deviate so strongly from the planned infrastructure that the scenario seems infeasible. Table 8 shows an overview of the necessary pipeline capacities in the scenarios.

Table 8 Infrastructure requirements

Route	Estimation (MW)	Limited (MW)	DN	Unforeseen (MW)	DN	Abundance (MW)	DN
Rotterdam North - Lansingerland	40	126	DN 300 (2x)	304	DN350 (4x)	460	DN350 (6x)
Lansingerland - Leiden	40	40	DN 250	73	DN 350	151	DN350 (2x)
Botlek - Rotterdam North	95	95	DN250 (2x)	95	DN250 (2x)	95	DN250 (2x)
Botlek - Rotterdam South	50	76	DN 350	293	DN350 (4x)	293	DN350 (4x)
Botlek - The Hague	90	334	DN350 (4x)	817	DN350 (10x)	933	DN350 (10x)
Europort – Botlek	200	200	DN350 (3x)	200	DN350 (3x)	200	DN350 (3x)
Rotterdam South – Dordrecht	40	40	DN 250	40	DN 250	40	DN 250

3.1.3 OVERVIEW POTENTIAL DESIGN OF A DISTRICT HEATING SYSTEM

In section 3.1.2, scenario options for the approach of the PZH were discussed. This resulted in the selection of three potential system designs that will be further investigated during the course of this research. Table 8 shows an overview of the main differences between the scenarios.

Table 9 Overview scenarios for the development of district heating from the perspective of the PZH

Name	Limited	Unforeseen	Abundance
Total demand (MW/PJ)	794/25	1587/50	1587/50
Share of demand connected to district heating	25%	50%	50%
Development of geothermal heat	Low	Low	High
Local (residual) heat sources	Yes	Yes	Yes
Residual heat in the Botlek and Europort	Yes	Yes	Yes
Total supply (MW)	5921	7656	7968

In the next few pages, the scenarios are discussed more in-depth. The next page is intentionally left blank to make sure the overviews of the scenarios are on two adjoining pages.

OVERVIEW LIMITED

The Limited scenario has a centralized, planned development of district heating. The market penetration rate remains low (25%). Because of the heat transport infrastructure, heat sources throughout the province can be used to supply heat locally. Figure 3 shows that gas plants represent the largest available heat source in the base-load, followed by coal plants and waste incinerators.

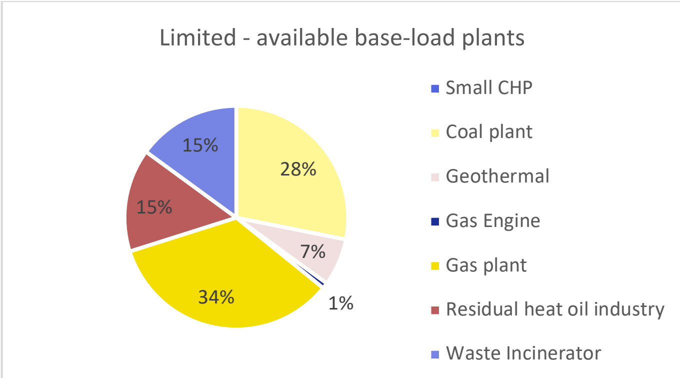


Figure 3 Available heat Limited scenario

Figure 4 shows that in the Limited scenario, there is a sufficiently high local base-load capacity in the clusters Dordrecht, Leiden, Rotterdam North and Rotterdam South. In the Lansingerland cluster the base-load capacity is only sufficient to supply 13% of the peak demand and in The Hague the base-load capacity is only sufficient to supply 24% of the peak demand, while this should be at least 30%.

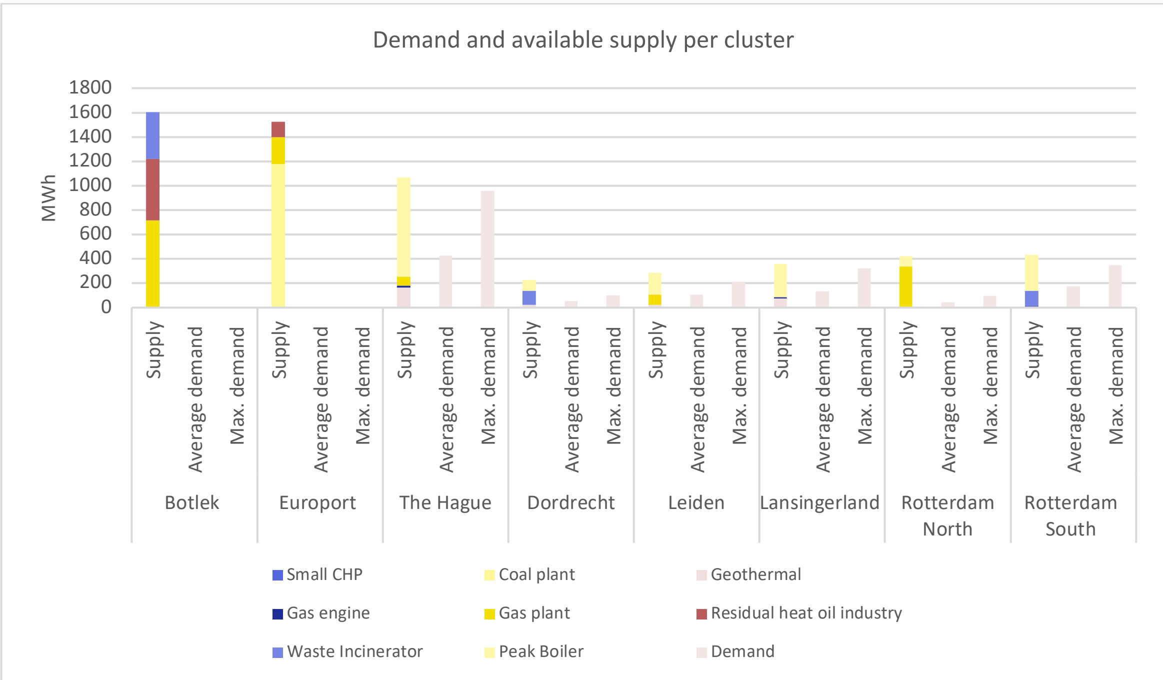


Figure 4 Demand and available supply per cluster Limited scenario

When the planned heat infrastructure is added to the design, there is sufficient base-load capacity in each of the clusters. The overview of the scenario is shown in figure 5. Figure 5 shows the average hourly demand, the maximum available hourly supply and the maximum storage capacity. The available hourly supply consists of the base-load and the peak-load plants.

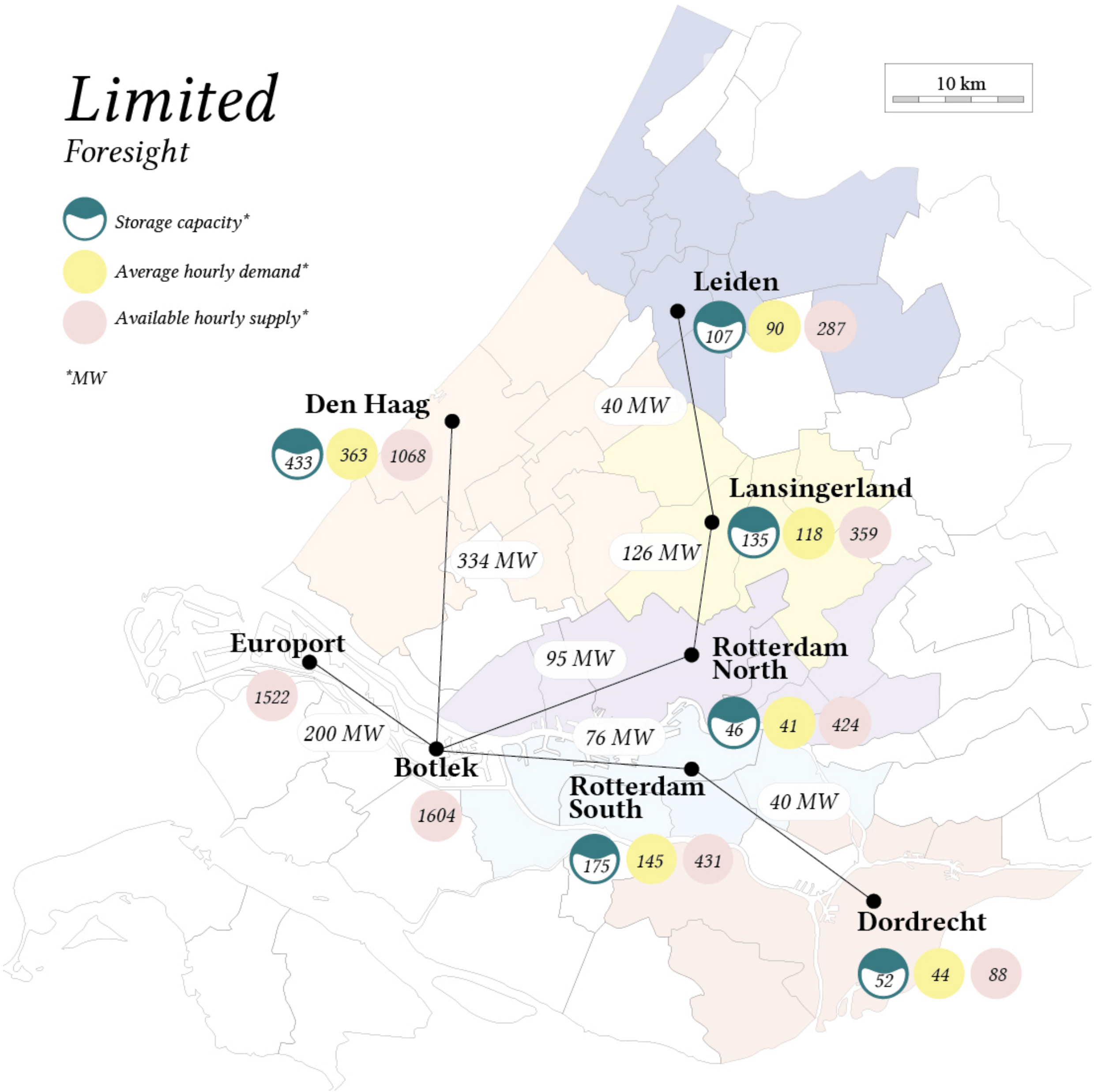


Figure 5 Overview input Limited scenario

OVERVIEW UNFORESEEN

The Unforeseen scenario has a centralized, planned development of district heating. The market penetration rate grows to 50%. Because of the heat transport infrastructure, besides local heat sources, heat sources throughout the province can be used to supply heat locally. Figure 6 shows the available plants in this scenario.

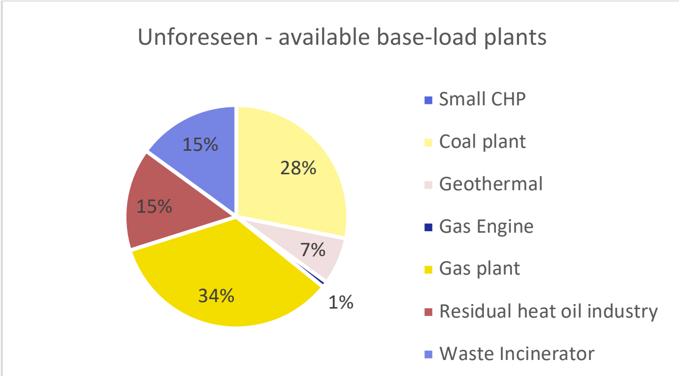


Figure 6 Available heat Unforeseen scenario

Figure 7 shows that only Dordrecht and Rotterdam North have a sufficiently high base-load capacity to supply the base-load locally. In all the other clusters, the base-load needs to be imported. As such, the heat transport infrastructure is necessary to avoid (semi-) permanent dependence on peak boilers. The required base-load can come from Rotterdam North, Botlek and Europort.

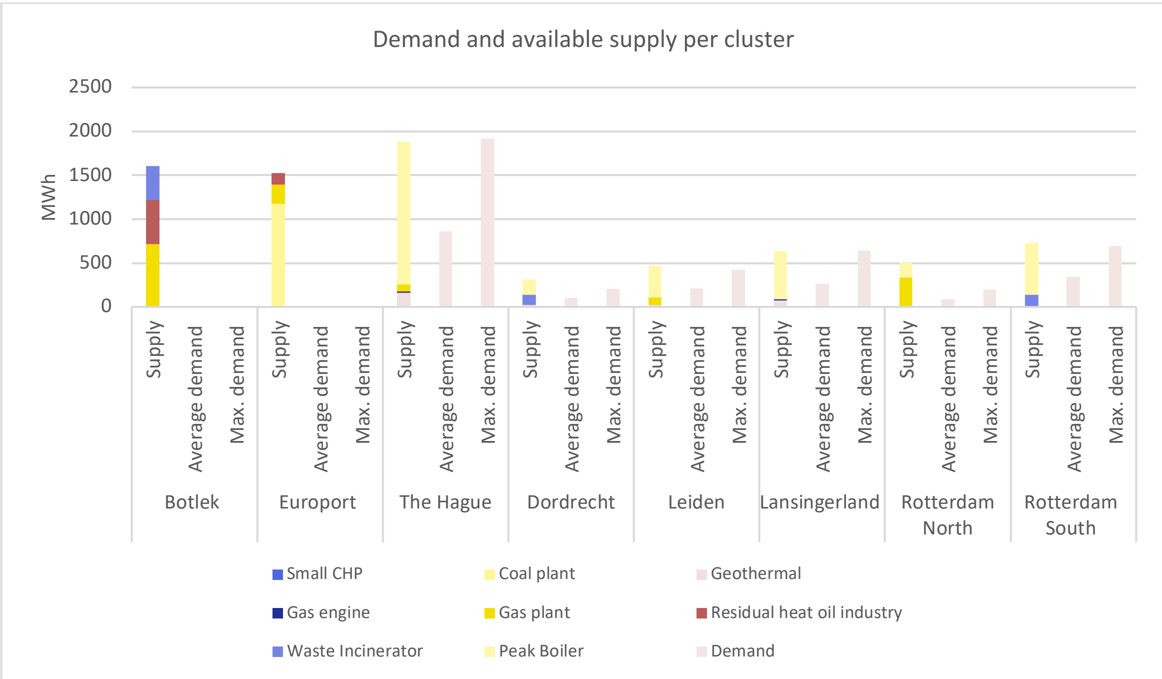


Figure 7 Demand and available supply per cluster Unforeseen scenario

Figure 8 shows the resulting system design, including infrastructure.

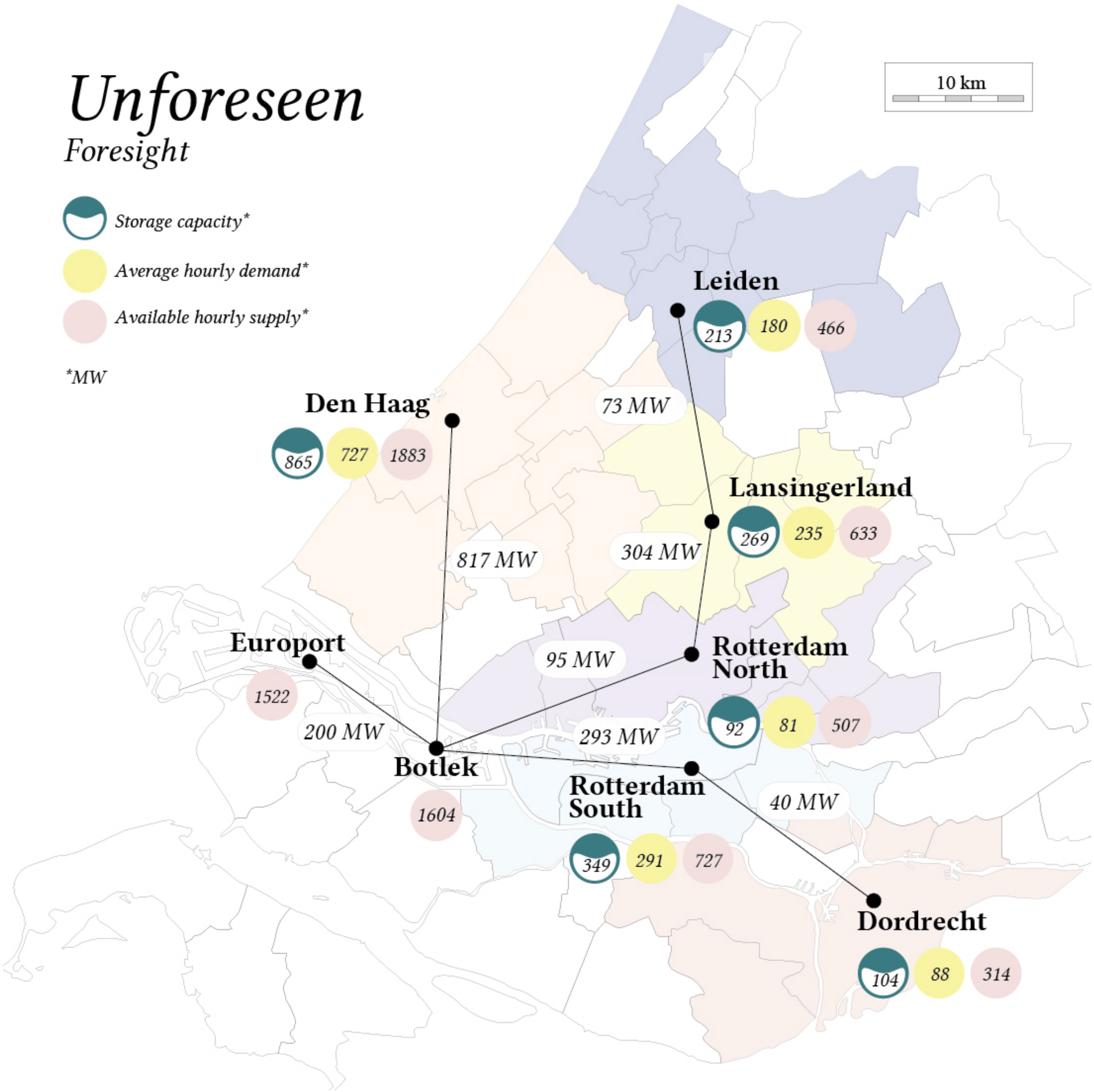


Figure 8 Overview input Unforeseen scenario

OVERVIEW ABUNDANCE

The Abundance scenario has a centralized, planned development of district heating. The market share for district heating grows to 50%. Besides this, the development of geothermal heat takes off. Figure 9 shows the available plants in this scenario.

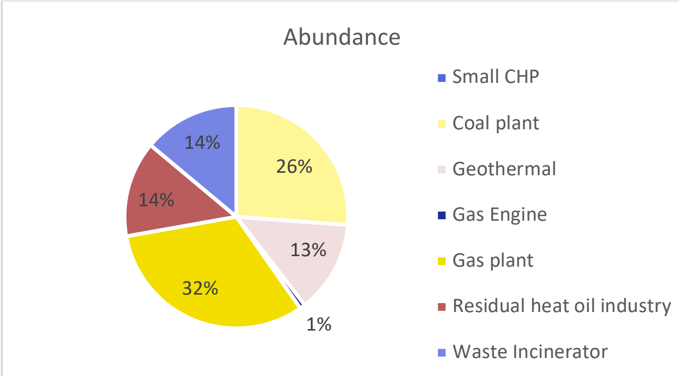


Figure 9 Available heat Abundance scenario

Figure 10 shows that Dordrecht, Rotterdam North and Leiden have a sufficiently high base-load capacity to supply the base-load locally. In all the other clusters, the base-load needs to be imported. However, the shortage in The Hague and Lansingerland is lower than in the Unforeseen cluster. The heat transport infrastructure is necessary to avoid (semi-) permanent dependence on peak boilers in these two clusters. The required base-load can come from Rotterdam North, Botlek and Europort.

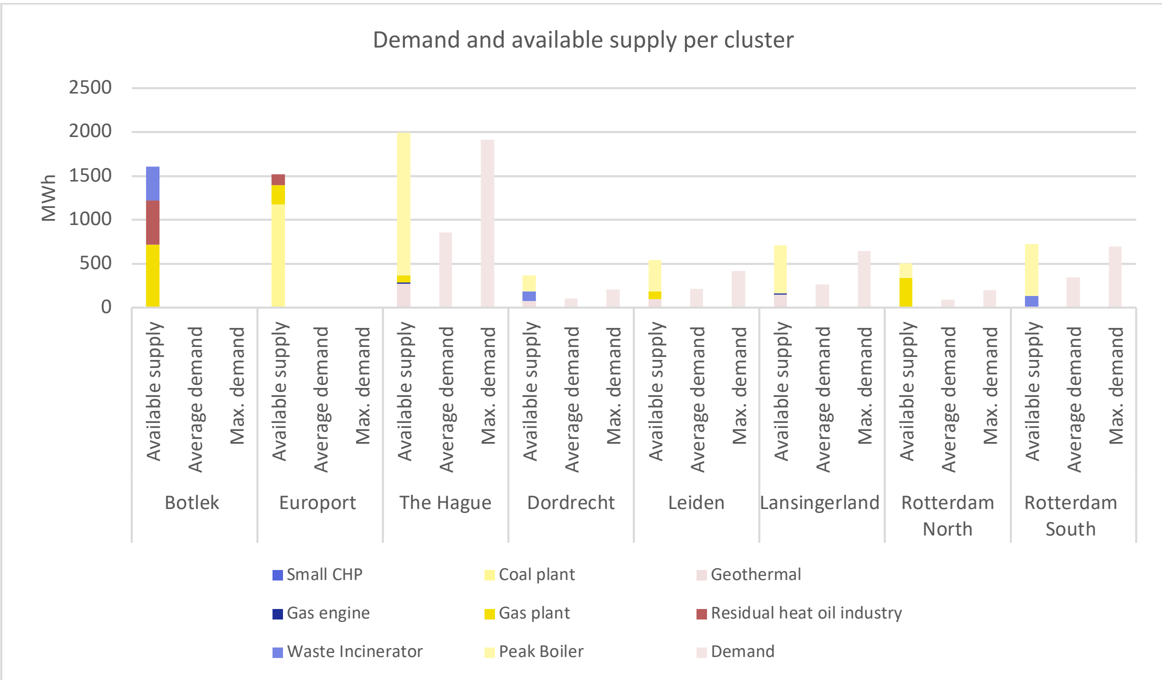


Figure 10 Demand and available supply per cluster Unforeseen scenario

The additional investments in geothermal heat in this scenario especially have a high impact on the Lansingerland cluster. The additional 75 MW geothermal heat overcomes the shortage observed in the Unforeseen scenario. Figure 11 shows an overview of the Abundance scenario.

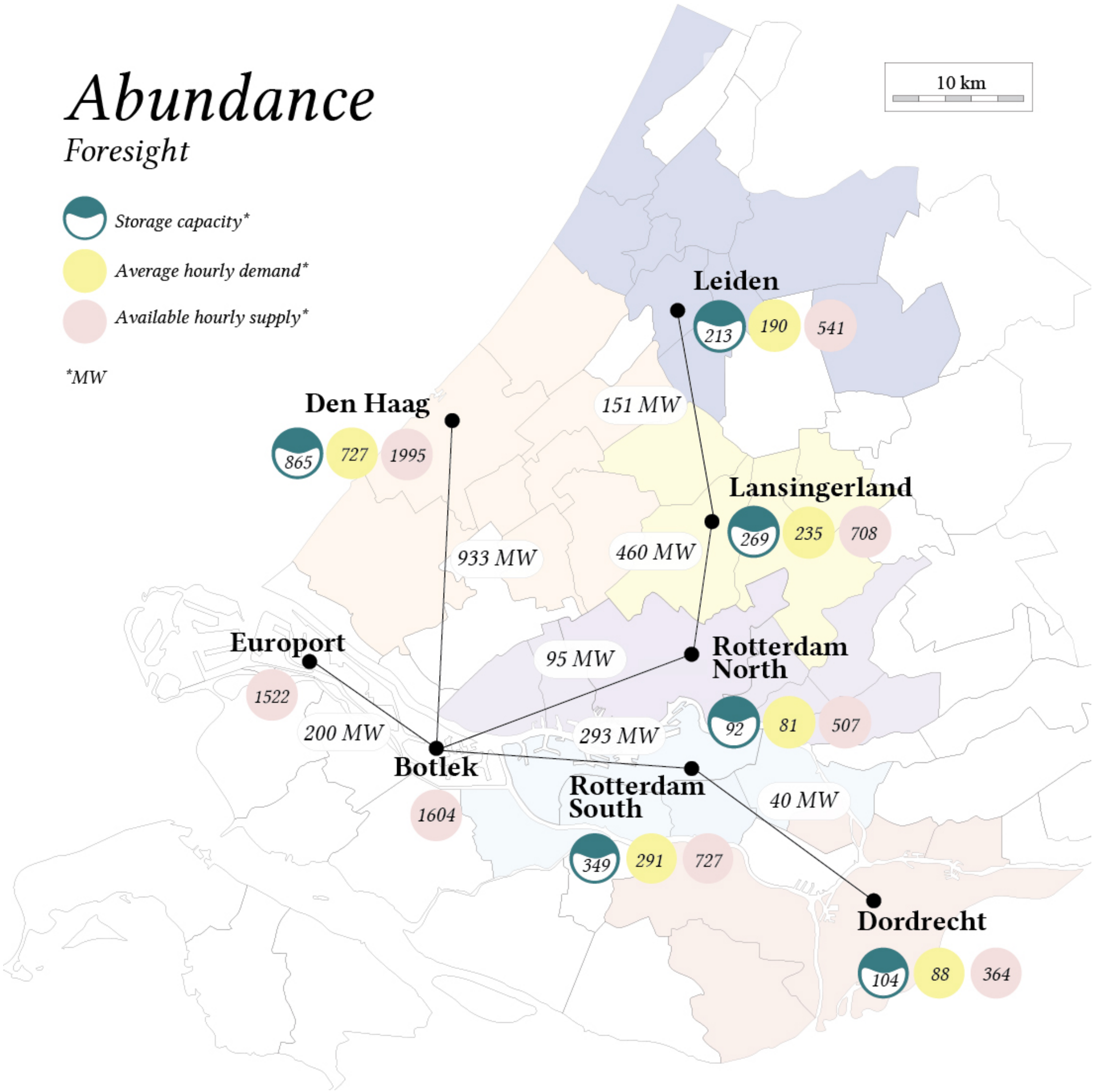


Figure 11 Overview Abundance scenario

3.2 THE APPROACH OF THE PBL

In this section, we will discuss the approach of the PBL conceptually (3.2.1), we will discuss the methods the PBL deploys to develop and (quantitatively) support their approach (3.2.2) and we will present the main design uncertainties the PBL foresees with regard to the development of district heating infrastructure (3.2.3).

3.1.2 CONCEPTUAL DESCRIPTION APPROACH

The PBL on the other hand foresees a market driven, distributed development of small-scale district heating networks, based on local technical and economic conditions. The completeness of the transition will depend on the market conditions for district heating and other alternatives for natural gas. Figure 12 shows an overview of the order in which the transition will take place if the approach of the PBL is followed.

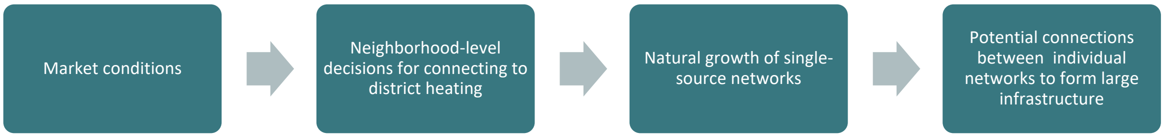


Figure 12 Sequentially of infrastructure development: approach of PBL

The PBL acknowledges that large, open district heating networks will provide opportunities to include and construct more sustainable heat sources to the network. However, PBL also foresees issues with regard to the large-scale of development district heating networks. Developing large-scale district heating requires significant investments with substantial risks with regard to the development of supply and demand of heat and the regulation of the heat sector, which is currently subject to change. In general, commercial parties are unable and unwilling to take these risks (Planbureau voor de Leefomgeving, 2017b).

The PBL has a radically different approach towards realizing a vision of the development of district heating in South Holland than the Province of South Holland (Planbureau voor de Leefomgeving, 2017b). The approach differs especially with regard to the structure and growth of the district heat network. This approach follows the historic development of district heating; usually a gradual process of network expansion, where the network start with a single base load plant and simple infrastructure, which is gradually expanded to connect more consumers and suppliers (Frederiksen & Werner, 2013). New base-load plants and storage facilities can be added to the network over time. Moreover, multiple smaller district heating networks can be connected to form a single infrastructure, which increases security of supply. The PBL expects that this process will be demand-driven. In addition, lead to gradual, local development of district heating, based on cost-minimizing behaviour of local heat consumers. To evaluate this type of network development, the PBL has implemented this logic in Vesta/MAIS, a GIS model that uses a rule-based optimization to calculate the development of the energy demand and supply in the built environment. This model is further explained in Appendix 1.

PBL thinks that in the future, district heating networks will develop from networks based on a single base load plant into networks that are connected to more than one heat source (Planbureau voor de Leefomgeving, 2017b). Nevertheless, the PBL does not further specify what options it foresees for this development of larger interconnected district heating networks. This will depend strongly on the location of supply and demand of heat and the selected temperature regimes (Planbureau voor de Leefomgeving, 2017b). Under current market and policy conditions, the development of district heating networks throughout South Holland will not really take-off. Only when the price of natural gas will increase step-by-step to € 2,25/ m³ in 2050, the transition will fully occur (Planbureau voor de Leefomgeving, 2017b). This is an increase of the current gas-price for households with € 1,65/ m³ and indicates that the gas-bill will have to increase by a factor 2.75. When this happens, the PBL expects that over 65% of the remaining heat demand will be supplied through district heating networks. The other 30-35% will be supplied through heat pumps and a few percent will remain natural gas or become green gas.

Main advantages of this approach are that it fits with the observed movement of local energy initiatives, which primarily focusses on the development of small-scale district heating systems based on sustainable heat sources. These local energy initiatives benefit from local public support (Planbureau voor de Leefomgeving, 2017b). Moreover, the approach demands relatively low upfront investments. Moreover, there is experience with this type of development of district heating systems, as it fits with the observed development of district heating infrastructure throughout Europe(Frederiksen & Werner, 2013). A main disadvantage of this approach is that there is a lack of understanding of the "end-state" of the system, which makes it difficult for parties to commit (Planbureau voor de Leefomgeving, 2017b). Moreover, this approach is driven by cost-minimization rather than transition scale. After the early stage in the transition, scaling-up may result in unnecessary high costs, as the initial infrastructure is designed for only the first group of consumers.

3.2.2 FORECASTING METHOD

The PBL builds its vision on district heating in 2030 vision on the result of a model run in the Vesta/MAIS model. The basis of the Vesta/MAIS model is the spatial distribution of the buildings in the Netherlands. Buildings include utilities, greenhouses and houses. Buildings, which house heavy industry, livestock and extensive agriculture, are not included. Data about households and utilities comes from the BAG dataset; this data set includes information like the building year, surface, purpose and location. Data about the greenhouses comes from the individual municipalities.

DEVELOPMENT OF DEMAND

The energy demand is split into four categories: heat, cold, electricity and hot water. For each building, the energy demand is calculated based on the following information ((CE Delft, 2016):

- Households: the model has a predetermined energy demand per type of building, use and building year. For example; the model distinguishes between family homes and student houses, the model distinguishes between high and low apartment buildings and the model categorizes buildings by building-periods of 10 years.
  Besides this, the model includes data about the improvements in energy efficiency of buildings that led to a registered improvement in the energy-label of the building.
- Utility buildings: the model has an energy demand value per square meter per type of utility building. Types of utility buildings are offices, shops, trading floors, garages, nursing homes, hospitals, educational facilities, gastronomy and other services.
- Greenhouses: the model has an energy demand value per square meter per type of crops, distinguishing between flowers, vegetables and others, and energy demand: necessity of lighting and heating.

The average temperature is calculated for areas of 100 m^2, so the energy demand can be corrected for changes in average yearly temperature. The heat demand consists of the demand for hot-water and space heating. The efficiency of the hot water and heating systems is determined based on an index number, which is set at 1 for current buildings. The energy-efficiency of greenhouses can be altered in the model, but is by default kept constant.

The future energy demand of households and utilities can be steered when designing model runs. The model can be forced to implement building specific measures for energy demand reduction. For the purpose of this study this is not done.

BUILDING AND AREA SPECIFIC INVESTMENTS

The Vesta/MAIS model simulates the investments energy demand and supply. The model distinguishes between two types of investments: 1) building specific investments and 2) area specific investments. The model first calculates the building specific investments and then the area specific investments. As such, in each optimization step the potential for area specific investments depends on individual changes people make to their buildings. An investment decision can be based on individual economic optimization, societal economic optimization or it can be enforced by pre-defined goals.

BUILDING SPECIFIC INVESTMENTS

The included building specific investments are insulation, solar-PV systems, solar boilers, electrical heat pumps and micro-CHP. Building specific insulation investments are included based on the label of the building, which indicates the insulation level of the building. The model evaluates what the most suitable spatial design is for fulfilling the energy demand, which consists of; heating, cooling, electricity and hot water demands. The decision to implement building specific measures can be enforced based on pre-determined values or can be based on cost calculations.

AREA SPECIFIC INVESTMENTS

The included area specific measures are district heating (based on geothermal heat, residual heat or district CHPs), heat-cold storage and natural gas networks. This research only focusses on the implementation of district heating networks. Heat-cold storage systems and new natural gas networks can substitute district heating networks and exist independently of district heating networks. As such, district heating networks compete with heat-cold storage systems and new natural gas networks.

DISTRICT HEATING

The application of district heating is restricted by location. Locations of current and potential residual heat sources are listed in the model input data. The user of the model can easily adjust this input data. Potential locations for geothermal wells are defined by area outlines. When economically feasible, district heating networks based on geothermal heat sources can distribute heat outside these outlines. Therefore, areas which are not suitable for a geothermal well, can still be connected to a district heating system with a geothermal well. A district heating system can only connect to a single heat source and the size of the network is limited by the maximum thermal capacity of this source.

TECHNOLOGICAL ADVANCEMENTS AND SOCIAL LIMITS

The model includes efficiency numbers for indoor heating systems (hot water production and central heating system) and complementary technologies, such as : solar PV, solar boiler, electrical heat pump, micro CHPs and electrical heaters. The efficiencies of these systems are modelled after current efficiencies but can be improved throughout the model run via a learning curve. By default, all existing buildings are connected to electricity and gas. There is one exemption, the buildings that have a pre-defined staring condition as they are connected to a district heating system based on a geothermal heat source. Buildings are build and demolished based on predefined rates. Buildings that are build during the model run do not necessarily connect to natural gas by default. The Vesta/MAIS model can incorporate estimations about the support base for alternative heating options and energy efficiency measures. The model contains information about the income of residents and ownership of houses per district. Moreover, the model includes information about the ownership of a building, the type of building and the building period. Based on this information, consumer groups and buildings can be excluded from the analysis.

SCOPE

The Vesta/MAIS model generates an output for the whole of the Netherlands. The BAG dataset functions as a starting point for modelling the development of the energy demand in the built environment. The BAG dataset contains spatial information about the built environment in The Netherlands. To limit computational power required for a model run, the size of the BAG dataset can be limited in scope. A so-called snapshot of the dataset can be made. A snapshot can be made based on coordinates or based on a shape file. The coordinates used to represent South Holland are shown in table 10. The coordinates are rijksdriehoeksmetingen, a Dutch system of coordinates. The snapshot is larger than the province of South Holland to capture the whole of the province. In the first part of the analysis, the data of the whole model run is used. Here, the area of the run is referred to as the greater area of South Holland. In a later stadium, when the two visions on district heating are analysed, the data is disaggregated to the level of municipalities and only the municipalities within South Holland are included in further analysis. The BAG-dataset that is used is dated the 8^{th} of January 2017.

Table 10 Coordinates snapshot BAG-data

x-min: Westerschouwen	37810800 mm	x-max: Schoonrewoerd	136357514 mm
y-min: Oolgtensplaat	411043007 mm	y-max: Bennebroek	481543151 mm

3.2.3 SYSTEM DESIGN

To evaluate what different options there are for the development of demand and supply, a sensitivity analysis was performed on the Vesta/MAIS model. The model-parameters for which a sensitivity analysis was performed were decided upon in consultation with model-experts from the PBL. The selected parameters are: WLO scenarios for economic and demographic development, the CO_2 price and the investment costs main heat infrastructure The detailed results of the sensitivity analysis can be found in appendix 2.

DEMAND

The Vesta/MAIS model calculates which neighbourhoods (PC4 level) will connect to a district heating network. It uses two criteria 1) is it possible to develop a local district heating network, and 2) is it financially attractive to switch from the current means of heating to a district heating network. The model calculates an average market penetration rate of district heating of 14% in the demand clusters defined in South Holland. This differs however strongly between the clusters (figure 13-18). Figure 13-18 show that the development of district heating is the highest in the Lansingerland cluster. In the municipalities within this cluster on average 34% of the demand will be connected to a district heating network. The market share is the lowest in the clusters of The Hague, where on average only 5% of the demand is connected to a district heating network.

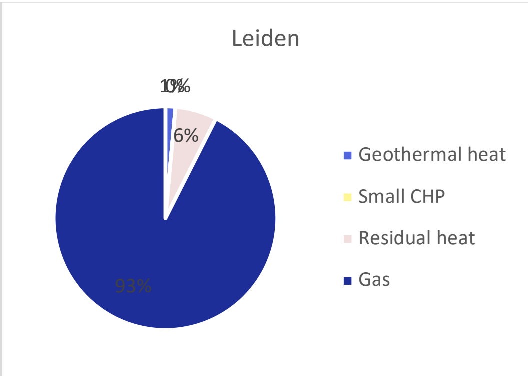


Figure 13 Market share district heating in Leiden 2030

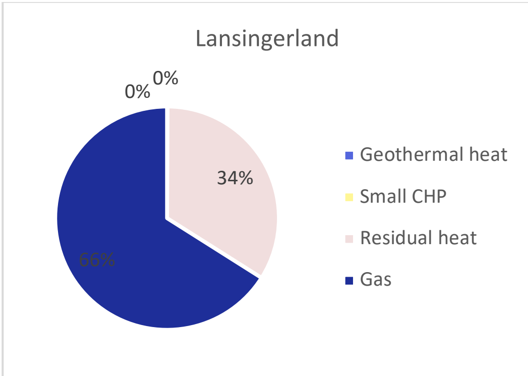


Figure 14 Market share district heating in Lansingerland 2030

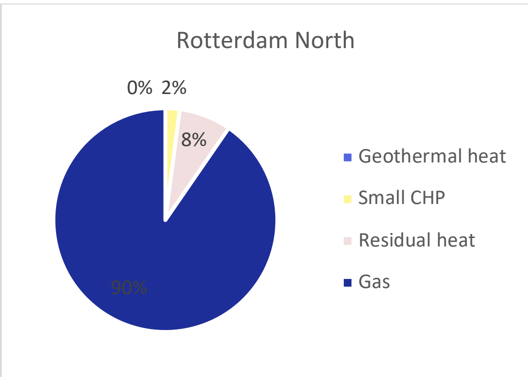


Figure 15 Market share district heating in Rotterdam North 2030

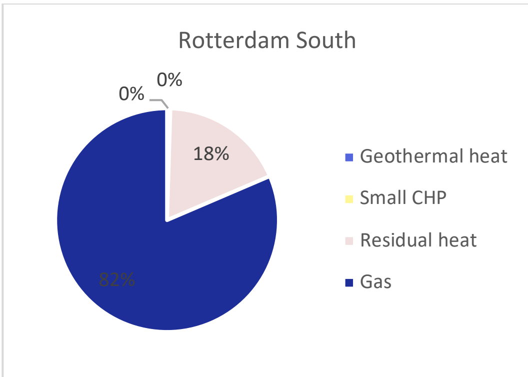


Figure 16 Market share district heating in Rotterdam South 2030

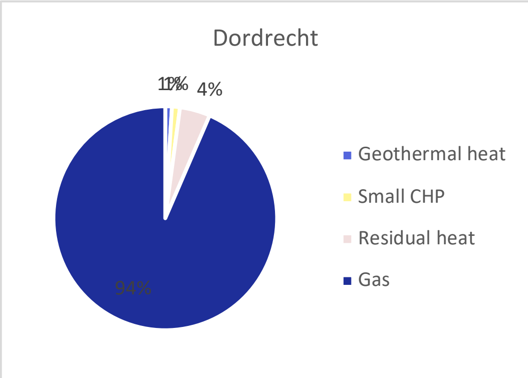


Figure 17 Market share district heating in Dordrecht 2030

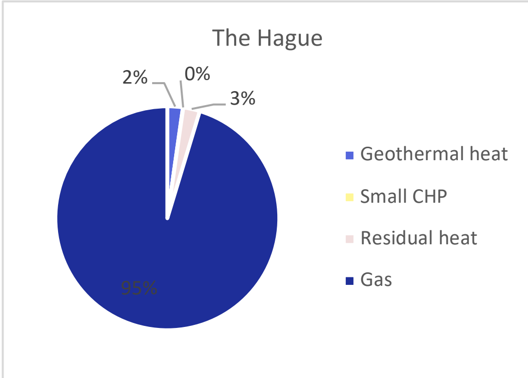
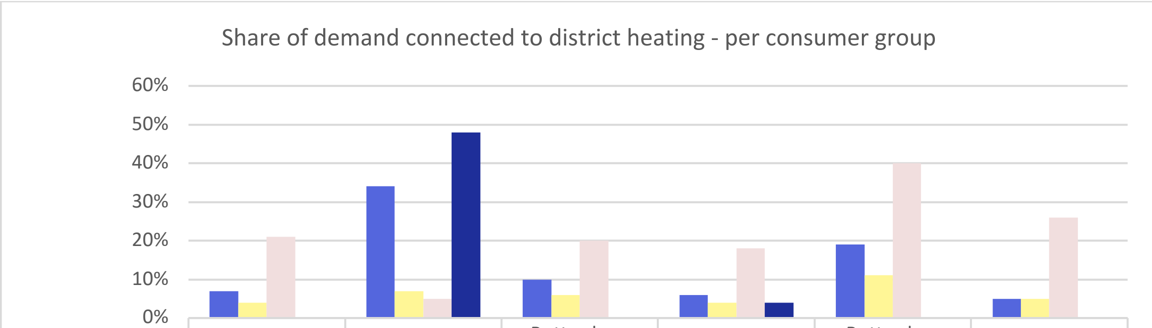


Figure 18 Market share district heating in The Hague 2030

The figures 13-18 also shows that the development of district heating strongly varies per consumer group. On average, utility buildings are most often connected to a district heating network, followed by households. However, in the cluster of Lansingerland, almost 50% of the greenhouses is connected to a district heating network. The sensitivity analysis in appendix 2 shows that the share of the consumers that will connect to a district heating network is not sensitive to the selected parameters. Therefore, we assume that the development of the demand in the approach of the PBL is stable and will result in the demand as described in figure 19.



	Leiden	Lansingerland	Rotterdam North	Dordrecht	Rotterdam South	The Hague
Total	7%	34%	10%	6%	19%	5%
Household	4%	7%	6%	4%	11%	5%
Utility	21%	5%	20%	18%	40%	26%
Greenhouse	0%	48%	0%	4%	0%	0%

Figure 19 Share of demand connected to district heating - per consumer group

SUPPLY

The input-data of the Vesta/MAIS model show that there is 3899 MWh of residual heat available in South Holland in 2030. Based on the definition of the clusters, 773 MWh lies within the scope of the available district heating networks in 2030. In addition, the model run shows that by 2030 there is almost 50 MWh of geothermal heat sources available.

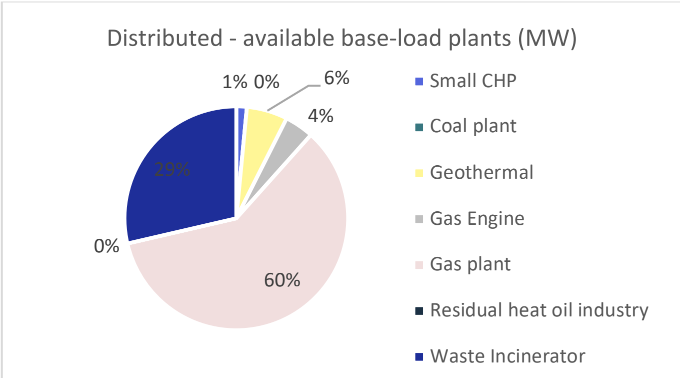


Figure 20 Availability heat Distributed scenario

The district heating networks based on geothermal heat sources are located in: Delft, Dordrecht, The Hague, Leiderdorp, Noordwijk, Rotterdam and Rijswijk. In addition, there are approximately 13 MWh of small (bio-based) CHPs –based district heating networks. These are located in: Barendrecht, Capelle aan de Ijssel, Delft, Dordrecht, Gouda, Vlaardingen, Lansingerland, Zuidplas and Leidschendam. In total there is 835 MW available base-load heat supply. Figure 20 shows the share of the different types of available base-load plants. Five of the municipalities the PBL expects will develop a district heating network are excluded from this research because of the scope of the heat clusters. These are: Gouda (Geothermal heat, small CHP), Hellevoetsluis (Geothermal heat, small CHP), Nieuwkoop (Small CHP), Zwijdrecht (Small CHP) and Goeree-Overflakkee (Small CHP).

Gas-plants represent the largest potential heat source, followed by waste-incinerators and geothermal heat sources. The availability of heat however, strongly differs per cluster. Figure 21 shows the total available heat capacity per cluster. Rotterdam North and Leiden depend on gas-fired electricity plants. Rotterdam South and Dordrecht strongly depend on waste incinerators. And only in The Hague there is a significant development of geothermal heat. In Lansingerland there are only a few gas-engines.

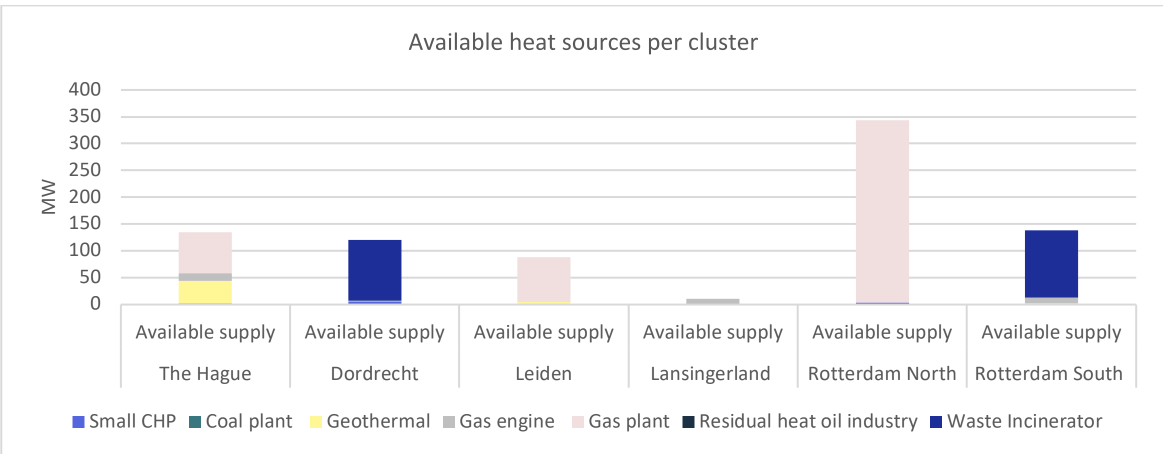


Figure 21 Available heat sources per cluster

The sensitivity analysis in appendix 2 shows that the development of heat supply options towards 2030 following the approach of the PBL is not sensitive to the model settings selected for the sensitivity analysis. Therefore, we assume that the development of the supply in the approach of the PBL is stable and will result in the supply-options as described in figure 21.

SCENARIO-SELECTION

The sensitivity analysis of the Vesta/MAIS model in appendix 2 shows that the development of demand and supply for district heating networks in South Holland as calculated by the Vesta/MAIS model output is not sensitive to the economic and demographic development scenarios, the CO_2 price and the investment costs in heat infrastructure. Therefore only one system design is considered for further analysis. This is the system design, which results from the Vesta/MAIS model under standard model settings in the year 2030. This system design is further referred to as the "Distributed" scenario. Figure 22 shows the district heating networks the Vesta/MAIS model expects to exist in 2030. The dark-grey coloured neighbourhoods (at PC4 level) indicate that there is a district heating network.

Figure 22 District heating in South Holland in 2030 according to the approach of the PBL

INFRASTRUCTURE

Following the logic of the PBL, district heating infrastructure is only developed when necessary to realize financially attractive district heating systems. The analysis of the base-load in appendix 5 shows that there is insufficient local capacity to supply the base-load in the Lansingerland, The Hague and Rotterdam South. In Rotterdam North and Botlek, the base-load is sufficiently high for the base-load for multiple. Based on the base-load requirement, the minimum capacity of this pipeline is determined (table 11).

Table 11 Pipeline capacities Distributed scenario

Route	Pipeline	DN standard equivalents
Lansingerland - Leiden	0	
Rotterdam North - Lansingerland	348	DN300 (x5)
Botlek - Rotterdam North	0	
Botlek - Rotterdam South	61	DN 300
Botlek - The Hague	9	DN 125
Europort – Botlek	0	
Rotterdam South – Dordrecht	0	

3.2.4 SCENARIO: DISTRIBUTED

In 3.2.3 we have developed an understanding of the demand, supply and infrastructure of district heating systems, that the PBL, based on the Vesta/MAIS model, expects will develop towards 2030. In this section, we will show how these components form a scenario about the district heating system in South Holland in 2030. We call this scenario "Distributed" as it results in a fairly unconnected distribution system, with a limited number of main heat transport pipelines. Figure 23 shows an overview of the average hourly demand, available supply and total storage capacity per cluster. The storage capacity we have not discussed yet. However, as we will explain in chapter 4, heat storage is an important means to reduce the necessity of peak-boilers, which reduces the environmental impact of district heating infrastructure. Therefore, they are included in the analysis. We now have an understanding of what the district heating system could look like towards 2030. However, we

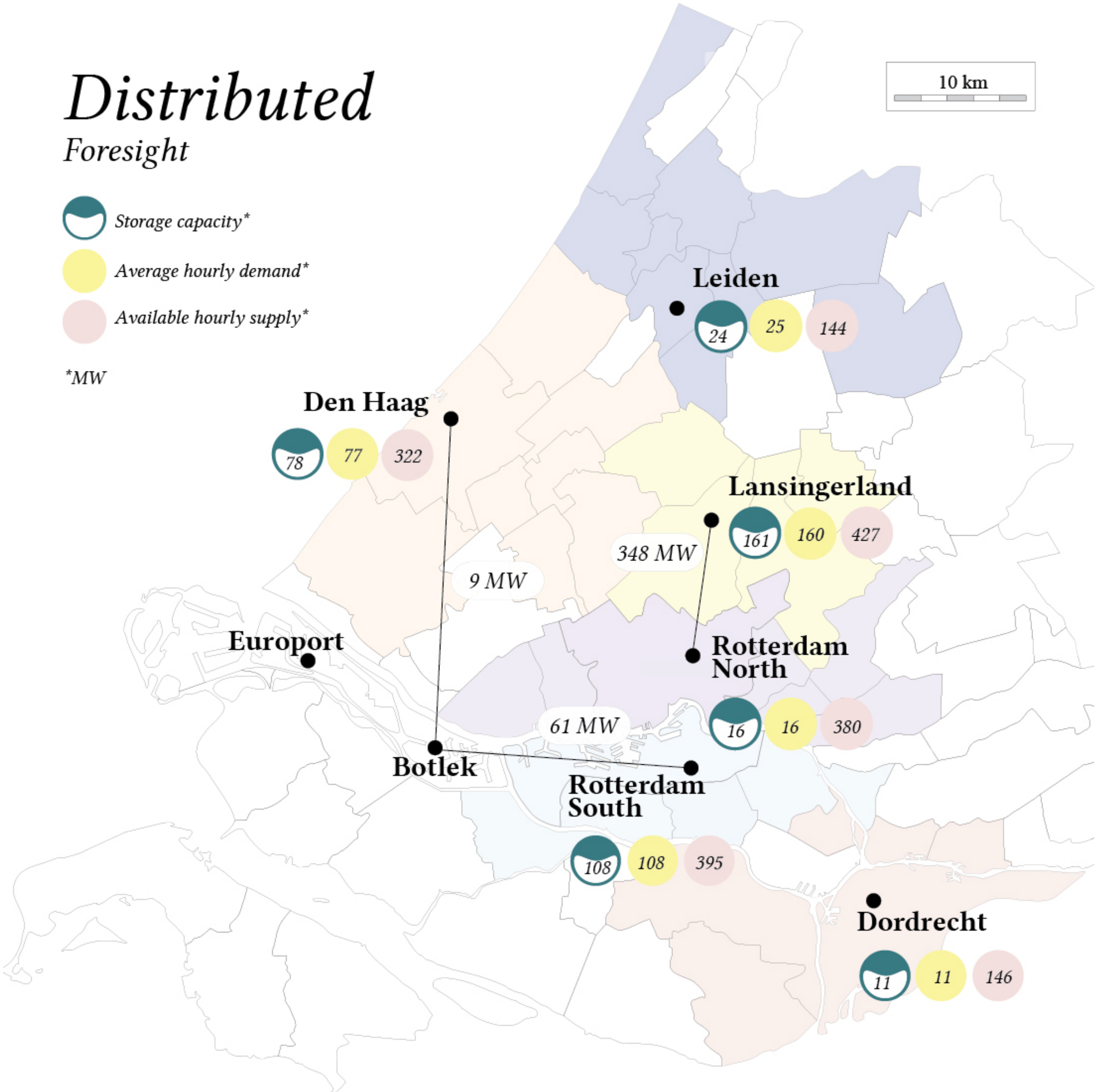


Figure 23 Overview input distributed scenario

3.3 RESULTS

In this section, we set-out the differences between the two approaches. We start with the conceptual differences (3.3.1), which are followed by the physical differences between the transition visions (3.3.2)

3.3.1 CONCEPTUAL DIFFERENCES

The two approaches differ with regard to: the driving force, the scope of the transition, the role of the municipality and the province, the expected transition outcome, the anticipated growth pattern of district heating infrastructure and the related approach for selecting heat sources. Moreover, both institutes adopt different methods to develop forecasts about the development of district heating. Table 12 shows an overview of the differences.

Table 12 Overview conceptual and methodological differences

	Local, market drive (PBL)	**Regional, plan driven (PZH)**
Conceptual differences		
Driving force	Market	Plan
Scope	Municipality	Province
Role of municipality	Director of the transition facilitates local development of district heating systems in collaboration with local market parties.	Organizes local demand in collaboration with Province
Role of Province	Coordinates between municipal plans	Organizes regional demand, supply and infrastructure in collaboration with municipalities and market parties
Result	Distributed small-scale district heating infrastructures	Large main district heating infrastructure
Market organization	Initially monopolies, later on potentially open markets	Open market
Growth pattern	Small district heating networks emerge over time because of local matches of supply and demand. Natural growth of these networks may later on result in connections via main transport pipelines to increase redundancy.	Initial demand and supply commitments result in the development of large main heat transport pipelines. These facilitate the further development of district heating throughout the province over time.
Resource approach	Mainly uses locally available heat sources.	Aims to optimize the use of available heat sources in the whole region.
Methodological differences		
Method to develop scenarios	Vesta/MAIS model	Process-driven research & scenario building

3.3.2 PHYSICAL DIFFERENCES

The two approaches for developing district heating in South Holland result in several potential transition pathways. In this thesis we have selected four scenarios for district heating systems in South Holland. This process is described in 3.1 and 3.2. One scenario is based on the approach of the PBL and three scenarios are based on the approach of the PZH. Based on these scenarios, some in-between conclusions can be drawn with regard to the differences between the potential system designs. The physical district heating system in these scenarios differ with regard to the consumers connected to district heating per cluster and per consumer group in 2030, the available geothermal heat sources in each cluster in 2030 and the route and capacity of main district heating infrastructure . An overview of the differences between the scenarios is presented in table 13.

Table 13 Overview market share, location and type of heat consumers connected to district heating infrastructure

Name	Distributed	Limited	Unforeseen	Abundance
Approach	The PBL	The PZH	The PZH	The PZH
Total demand connected (MW/PJ)	396/12	794/25	1587/50	1587/50
Share of demand connected to district heating	14%	25%	50%	50%
- **Households**	6%	25%	50%	50%
- **Utility buildings**	32%	25%	50%	50%
- **Greenhouses**	12%	25%	50%	50%
Share of demand connected to district heating				
- **Leiden**	7%	25%	50%	50%
○ **Household**	4%			
○ **Utility**	21%			
○ **Greenhouse**	0%			
- **Lansingerland**	34%	25%	50%	50%
○ **Household**	7%			
○ **Utility**	5%			
○ **Greenhouse**	48%			
- **Rotterdam North**	10%	25%	50%	50%
○ **Household**	6%			
○ **Utility**	20%			
○ **Greenhouse**	0%			
- **Dordrecht**	6%	25%	50%	50%
○ **Household**	4%			
○ **Utility**	18%			
○ **Greenhouse**	4%			
- **Rotterdam South**	19%	25%	50%	50%
○ **Household**	11%			
○ **Utility**	40%			
○ **Greenhouse**	0%			
- **The Hague**	5%	25%	50%	50%
○ **Household**	5%			
○ **Utility**	26%			
○ **Greenhouse**	0%			
Development of supply				
- **Development of geothermal heat**	Distributed	Low	Low	High
- **Local (residual) heat sources**	Yes	Yes	Yes	Yes
- **Residual heat in the Botlek**	Yes	Yes	Yes	Yes
- **Residual heat in the Botlek**	No	No	No	No
- **Total available (base-load) supply (MW)**	820	4172	4172	4484
Infrastructure (MW)				
• **Lansingerland - Leiden**	0	40	73	151
• **Rotterdam North - Lansingerland**	348	126	304	460
• **Botlek - Rotterdam North**	0	95	95	95
• **Botlek - Rotterdam South**	61	76	293	293
• **Botlek - The Hague**	9	334	817	933
• **Europort – Botlek**	0	200	200	200
• **Rotterdam South – Dordrecht**	0	40	40	40

This results in an overview of the physical differences related to the transition visions of the PBL and the PZH. Moreover, it results in a set of uncertainties related to the two approaches (table 14).

Table 14 Overview of physical differences and related uncertainties

	Local, market drive (PBL)	Regional, plan driven (PZH)
Differences with regard to expectations		
Distribution of demand	Unequal distribution of demand over geographical areas and between consumer groups. Main regions for district heating are Rotterdam and Lansingerland. Consumers will mostly consist of utility buildings and greenhouses.	Equal distribution of demand over geographical areas and between consumer groups.
Expected market share	Depending on the district, in the range of 5%-34%	In the range of 25%-80%
Expected infrastructure	Main heat infrastructure between: Rotterdam North and Lansingerland, Botlek and Rotterdam North and Botlek and The Hague.	Full development of heat-roundabout.
Uncertainties		
Demand	The extent to which residents and local companies are willing and able to take action in the transition.	The extent to which residents are willing to conform to the transition plans.
Supply	The willingness and ability of owners of locally available heat sources to supply heat. The willingness and ability of (local) parties to develop geothermal heat sources.	The willingness and ability of owners of regionally available heat sources to supply heat. The willingness and ability of (local) parties to develop geothermal heat sources.
Infrastructure	The necessary infrastructure capacity for current (and future) heat demand.	The necessary infrastructure capacity for the total future heat demand.

3.4 CONCLUSION

In this chapter, we have seen that the approach of the PBL and the PZH for the development of district heating infrastructure differ with regard to the concepts underlying the transition, the methods the organizations deploy to develop foresights and their transition vision. The PBL adopts a local market driven perspective on energy transitions, forecasts depend on the Vesta/MAIS model. The PZH adopts a regional, plan driven perspective on energy transitions, the approach is plan driven and the forecasts depend on process driven knowledge development.

To further evaluate the approach of the PBL and the PZH we have developed scenarios for the development of district heating based on these approaches. The PZH finds the transition relatively unpredictable. In consultation with the PZH, we have selected two highly uncertain data inputs: the availability of geothermal heat and the market share of district heating. Based on these two inputs we have selected three scenarios, representing a low market share (25%) with a low development of geothermal heat (285 MW), a medium-high market share (50%) with a low development of geothermal heat (285 MW), and a medium-high market share (50%) with a high development of geothermal heat (600MW). The PBL however assumes a certain predictability in their forecast, which depend on the Vesta/MAIS model. In consultation with the PBL we have selected three model inputs: a scenario for economic and demographic development (high/low), the CO_2 price in €/ton (10, 37 (default), 50, 100, 150 and 300) and a subsidy on primary heat infrastructure (0%, 10%, 25%, 50%, 75%, 100%). All of these inputs only marginally affected the market share of district heating and the development of the total heat demand. Therefore, we have selected a single scenario for the approach of the PBL. This scenario has a market share of 14% and an availability of geothermal heat of 50 MW.

These four scenarios sketch a picture of what the district heating infrastructure in 2030 could look like if we were to follow their approach. Based on the insights we have gained in this chapter, we do not know what the potential differences are in investment costs between the different scenarios we have developed in this chapter. Moreover, we do not know how these systems could perform in terms of CO_2 abatement. More importantly, we do not know how the uncertainties and limitations we have identified actually affect the investment costs and potential CO_2 abatement that can be realized through developing district heating infrastructure. Therefore, in the next two chapters, we will develop two simple models that can be used to gain insights in the investment costs and potential CO_2 emissions from district heating network operation.

4.

DEVELOPING AN ECONOMIC DISPATCH MODEL FOR DISTRICT HEATING NETWORKS

In chapter 2 we have established that there are currently no models available that can simulate district heating network operation, based on the (high-level) data and design specifications currently available for the two approaches for developing district heating in South Holland. Moreover, there is no model available that can calculate the cost-efficient development for both approaches. However, in chapter 3 we have established that there is a need to gain insights in the risks related to the uncertainties within the two approaches for district heating, with regard to the costs of CO_2 abatement. Therefore, we will developed two models that can support gaining insights in the effects of these uncertainties in the approaches, on the transition objective. The first model is an economic dispatch model, which can simulate district heating network operation under the assumption that it functions as perfect market. That model is described in this chapter 4. The second model is a model that can calculate investment costs and fixed costs. That model is described in chapter 5.

The objective of this chapter is to develop a model that is capable of simulating the dispatch decision of a complex district heating system, with multiple producers and consumers, and a network that consists of one or more main heat transport pipelines. The chapter starts with the system description (4.1), introducing all components of the district heating networks and their function. Section 4.2 contains the model requirements and 4.3 contains the decisions with regard to the model scale and scope. Section 4.4 contains the model description and section 4.5 contains the verification, validation and sensitivity analysis of the model. In 4.6, we compare the input data with alternative datasets. In addition, 4.7 contains a discussion and conclusion about the models fitness for purpose.

4.1 SYSTEM DESCRIPTION

In this section, we will describe the main components of district heating infrastructure. Moreover, we will discuss the main concepts underlying district heating network operation. In addition, we will briefly reflect on dispatch mechanisms in district heating systems. This description of the district heating system operation has the purpose to serve as a basis for a cost-minimizing dispatch model, which under the assumption of perfect scenario and rational (cost-minimizing behaviour), resembles the simulation of a district heating system operation. For this reason, the district heating system is discussed in terms of flows (transport) and processes (production and consumption) and the related operational cost components.

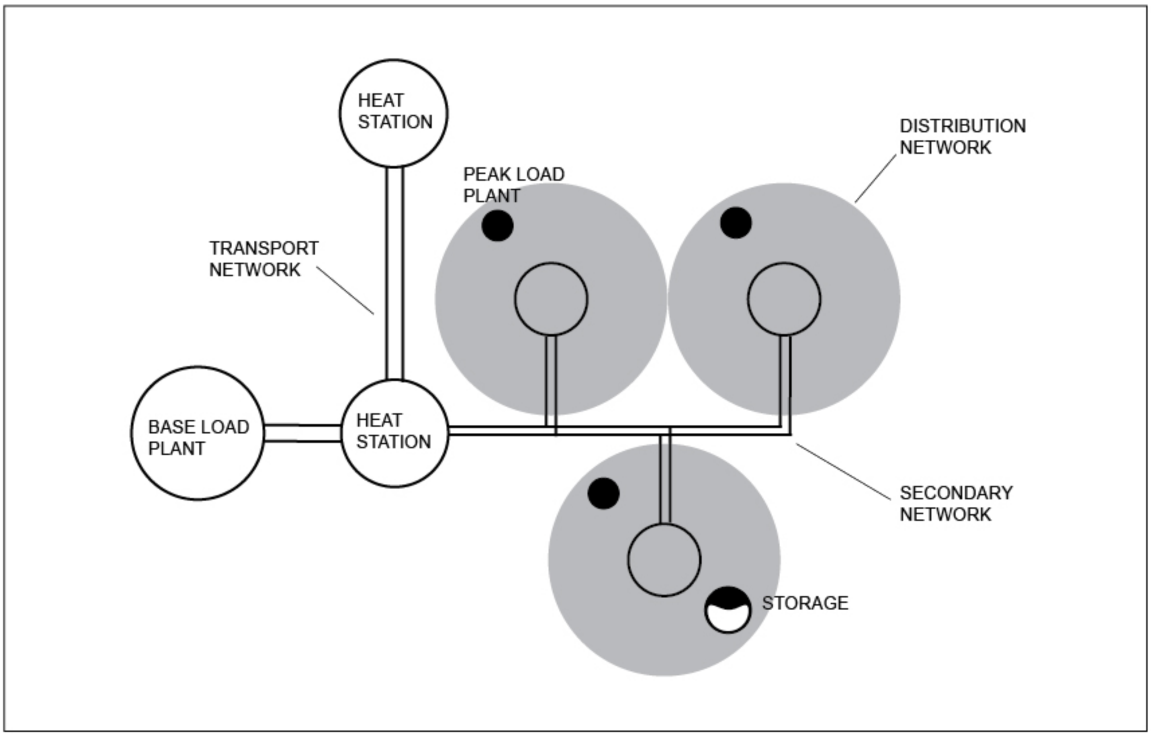


Figure 24 Conceptualization district heating network

On the highest level, a district heating system generates and distributes heat in the form of hot water from one or more suppliers to one or more consumers. Conceptually, district heating systems consist of the following components (figure 24):

1. Base load plant(s)
2. Transport infrastructure
3. Heat stations (incl. peak load plants)
4. Secondary infrastructure (incl. side pipelines)
5. Distribution network
6. Substations
7. Heat storage

In section 4.1.1 to 4.1.8 all components of a district heating network are discussed individually.

4.1.1 ROLE OF BASE-LOAD PLANTS AND PEAK-LOAD PLANTS

District heating networks have two types of heat source: base-load plants and peak-load plants. Base-load plants are the plants that run throughout the largest part of the year. Depending on the supply temperature, base-load plants can be different types of heat sources; these include residual heat from industrial processes; residual heat from electricity production; geothermal heat and other low-temperature heat sources, like solar thermal heat and residual heat from datacentres or swimming pools. Base-load plants should have a sufficiently large capacity to supply at least 30% of the peak demand (CE Delft, 2016). Peak-load plants complement base-load plants. Peak-load plants are located closer to the heat consumers (at the heat station or in the secondary network) and are used during peak-demand hours. Peak-load plants are also used to quickly respond to changes in the heat demand, as district heating networks can suffer from great time-delays depending on the size of the network. Peak-load plants should have a sufficiently large capacity to supply at least 85% of the peak demand (CE Delft, 2016).

Mass flow rates and temperatures can be varied to match heat supply and demand. Based on this, each plant should contain information indicating the speed at which it can increase or decrease its heat production. District heating networks are inherently slow in responding to demand signals. Therefore, demand forecasting is necessary to optimize heat production, mass flow rates and temperatures.

4.1.2 PRIMARY HEAT TRANSPORT INFRASTRUCTURE

The primary heat transport pipeline (transport network) transfers heat from the base-load plants to the heat stations. The variable costs of heat transport consist of the (pumping) power consumption and the heat losses. The power consumption for the pumping is determined by the mass flow rate, the pressure difference, the annual network operation hours, and the pump efficiency (Nussbaumer & Thalmann, 2016). The circulation pump of the network must generate sufficient pressure difference between the supply and return pipes in the peak load situation to guarantee that each consumer can be supplied with heat. The total pressure drop is larger in long district heating systems. Therefore, larger district heating systems require more pumping power. The temperature loss depends on the supply temperature, return temperature, pipe length, isolation, pipe diameter and flow speed. Besides this, it depends on the annual operation hours of the network and the number of full-load hours. Primary heat transport suffers from relatively low temperature losses in comparison to the secondary infrastructure, and the distribution network. The PZH expects approximately 4% heat losses in the primary heat infrastructure.

TEMPERATURE REGIMES

For this study, the assumption is made that the supply temperature of the district heating networks lies in the range of 90-95 degrees Celsius. The return temperature lies in the range of 60-70 degrees Celsius. This in line with existing district heating networks (Lund et al., 2014). The expectation is that towards the next generation district heating systems, these temperature will further decrease (Lund et al., 2014). Lowering the temperature of a district heating network over time, as demand declines through for example insulation is possible. However it requires (substantial) changes to the existing infrastructure (Rämä & Sipilä, 2017), is a relatively new and unexplored technique (Lauenburg, 2016) and may have negative results on existing infrastructure and network operation, such as legionella (Rämä & Sipilä, 2017) and higher pumping costs (Çomakli, Yüksel, & Çomakli, 2004). On the contrary, lower supply temperatures open up new possibilities for heat sources, result in lower thermal losses, because of the smaller temperature difference between the fluid and the surroundings and could potentially result in lower consumer prices for heat (Rämä & Sipilä, 2017).

4.1.3 THE HEAT STATIONS AND THE SECONDARY HEAT NETWORK

Heat stations connect the primary pipeline to the secondary heat transport infrastructure. Heat transport in the secondary infrastructure and in the distribution network leads to significant heat losses. The average thermal loss for secondary networks and distribution networks is 15%. These losses vary roughly between 3% during winter and 25% during summer (International Energy Agency, 2013). The target value for thermal losses in distribution networks is 10%, this target value enables economic operation of district heating networks (Nussbaumer & Thalmann, 2016). Pipeline length is a major contributor to heat-loss, especially in the secondary and distribution network. Therefore, high demand-densities are a prerequisite for affordable district heating.

The relative heat losses in summer are higher than in winter. This is a result of the higher return temperatures due to recirculation of hot water during summer (Himpe, Efrain, Rebollar, & Janssens, 2013). Moreover, during summer the heat demand is relatively low. This results in larger temperature drops over the length of the pipeline. During winter, normal temperature drops are 1-2 degrees Celsius. During summer, temperature drops are usually 5-10 degrees Celsius, but they can also be as high as 20 degrees Celsius (Frederiksen & Werner, 2013).

4.1.4 THE SUBSTATION AND THE DISTRIBUTION NETWORK

The secondary infrastructure connects the heat station to multiple substations, which are connected to a distribution network. The distribution network brings the heat to the final consumer. Substations have a control function. They consists of heat meters, circulation pumps and a control system (Gustafsson & Sandin, 2016). The distribution network connects the end-consumer of the heat. Distribution networks usually have a length of no more than a few meters per household. The heat losses in the distribution network are the highest.

4.1.5 CONSIDERATIONS WITH REGARD TO THE HEAT DEMAND

The heat demand consists of the demand for hot water and the demand for space heating. The demand for space heating depends on the hour-by-hour consumption pattern of the consumer and varies as a result of changing seasons. Physically, heat demand for space heating is determined among other things, by ambient temperature, indoor temperature, building materials, construction structure, and weather conditions (Ma et al., 2014). The hot water demand is also not constant throughout the day and year. During summer, the demand for hot water is approximately half of that during winter (Frederiksen & Werner, 2013). The share of domestic hot water supply in the energy consumption is continuously increasing, as the demand for space heating is decreasing while the hot-water demand remains constant (Nussbaumer & Thalmann, 2014). This means that the load variation patterns for hot tap water will become increasingly important in planning DH operation.

For planning district heating infrastructure, it is crucial to have accurate estimations of the heat demand. The feasibility of a district heating network depends on the density of the heat demand and the distance between the heat source and the consumers. *''An important parameter to assess the cost effectiveness of a DH system is the linear heat density which is defined as the ratio of the annual heat delivered to the total length of the DH piping and network. High linear densities increase the cost effectiveness of the DH system.''*(International Energy Agency, 2013) This has two reasons; firstly, high linear heat densities correspond to relatively low investment costs; And secondly, Cooper et al. (2016) show that lower linear heat density can have significant effects on the heat losses in pipelines.

4.1.6 OPTIONS FOR INCLUDING HEAT STORAGE

There are several arguments for including heat storage in a district heating network. Energy storage systems provide an effective way to help decoupling the energy production and the energy demand (Noussan et al., 2017). In addition, thermal energy storage makes it easier to recover industrial excess heat from batch processes and the thermal storage tanks can be used as a back-up system in case of a major water leakage or disruption in supply (Gadd & Werner, 2015). However, the main purpose of heat storage is the storage of the excess of heat production at night in order to match a part of the morning peak request without the need to activate peak load plants (Noussan et al., 2017). "*Heat load variations, both seasonal and daily, generate increased costs in district heating systems….One way to handle the variation, and the one that is mostly used, is to have heat storages''*(Gadd & Werner, 2013, p. 50). Heat storages can reduce the utilization of peak load plants, especially during the morning peak.

The optimal capacity of the heat storage is strongly connected to the relative amount of relative peak load (Gadd & Werner, 2013). *''Storage sizing strongly depends on the available heat technologies and the total heating demand.''*(Pavi et al., 2017, p. 13) A study of Swedish DH networks performed by Gadd and Werner (2013) shows that daily variations of heat demands are between 17% and 28% of the annual average demand. Hourly variations of heat demand are between 3% and 6% of the daily average (Eller, 2015; Gadd & Werner, 2013). For now, we will assume that the same variations can be expected in Dutch networks.

There are four types of thermal storage currently applied for DH purposes (table 15) (IRENA, 2013). The first type of thermal storage is thermal storage in the transport and distribution network; the temperature of the network can be increased temporarily. This can also be a means to increase the capacity of the system. The second type of thermal storage is thermal storage in water tanks, also called sensible thermal energy storage. The third type of thermal storage is underground thermal energy storage, which includes borehole storage and aquifer storage. Finally, the fourth type of thermal storage is thermal storage in heavy buildings. By slowly increasing and decreasing the temperature inside the building, the building functions as a heat buffer. This is particularly interesting in buildings with high thermal mass, which contain or are constructed of materials that can easily store heat, such as concrete.

Table 15 Overview of currently applied heat storage methods for DH

	Type of storage	Function
1	Network	Buffer short-term fluctuations in supply and demand of heat. Increase or decrease the network capacity
2	Water tanks	Depending on the size; buffer hourly or seasonal fluctuations in supply and demand of heat.
3	Underground storage	Borehole storage: seasonal storage of heat Aquifer: seasonal storage of cold
4	Heavy buildings	Buffer short-term fluctuations in supply and demand of heat.

Hot water buffers are a common and cost-effective type of heat storage (IRENA, 2013). The cost of a complete system for heat storage in a water tank ranges between €0.1-10/kWh, depending on the size, application and thermal insulation technology (IRENA, 2013). The efficiency of thermal heat storage systems lies between 50% and 90% (IRENA, 2013).

4.1.7 NETWORK OPERATION MECHANISMS

Operational planning and control is used to match supply and demand over time. Operational planning is based on the objective to minimize the operational costs, while meeting the heat demand. The planning and control can be based on both physical constraints on the plant and on the network, the dynamics in the network (temperature loss, pressure loss and time delay) and the marginal costs of network operation and heat production. When the heat sources consist of residual heat from electricity plants, the operational planning can also depend on the electricity market. When optimizing district heating network operation, there is a need for long optimization horizons of at least one year, in order to capture seasonal variations, and a small time step of 1 h or less, to capture intraday variations (Pavi et al., 2017). In addition, due to the slow nature of district heating systems, load-prediction is an important aspect of the network operation (Sakawa, 2016).

4.1.8 MARKET STRUCTURE

District heating systems in South Holland have a monopolistic nature. The heat networks in South Holland are privately owned and most networks have a single heat supplier (Province of South Holland, 2017a; Schepers & Van Valkengoed, 2009). Heat consumers are therefore dependent on their heat supplier and cannot choose where the heat comes from (ACM, 2016). Heat transactions are supported via bilateral supply contacts with periodically changing tariffs connected to the gas price (Eneco, 2016). For consumers with a connection smaller than 100 kW, the price of heat is capped by the "not more than usual" principle, which limits the price of heat to the price of the avoided use of natural gas (ACM, 2016).

There are signals that the current market organization for district heating systems will change (Kamp, 2016). While it is unclear what the guidelines for new market designs will be, several parties in South Holland expect a more open and competitive market, rather than the current monopolies (Province of South Holland, 2017a; Warmte Koude Zuid-Holland, Alliander, Berenschot, Agro Energy, E.on, Prominent, Provincie Zuid-Holland, LTO Glaskracht, 2015). An open heat market can remove the existing market barriers for new heat producers. Moreover, it could facilitate a cost-efficient dispatch decision and it could allow monetary policy measures to facilitate preferential (low-emission) heat sources. Requirements for an open market for heat are (Warmte Koude Zuid-Holland, Alliander, Berenschot, Agro Energy, E.on, Prominent, Provincie Zuid-Holland, LTO Glaskracht, 2015):

- Price-differentiation between location, based on transport constraints and/or transport losses.
- Transparency on the CO_2 content of heat, and potentially inclusion of the CO_2 emissions in the dispatch decision.

4.2 MODEL REQUIREMENTS

As discussed in 2.1.3 we will develop an economic dispatch model that will simulate district heating network operation under the assumption of perfect competition (homogeneous product, no market power, perfect information, no market barriers and no transaction costs). Under perfect competition, the bidding ladder is based on the marginal costs of heat production. Under this condition, the dispatch decision can be approached as a mixed integer linear programming problem.

The optimization objective is to satisfy the heat demand for each consumer with the lowest marginal cost plants, given the physical constraints on demand, production, transport and storage and economic data on the marginal costs of heat production, the costs of heat losses and the costs of CO_2 emissions. Because of seasonal and hourly fluctuations in the heat demand, the appropriate time-step to determine the dispatch schedule of the heat sources is an hour and the minimum time horizon is a year. To include heat storage, the model optimizes the dispatch-decision over seven time-steps. Moreover, the model output is the optimal hourly dispatch schedule for all available heat sources in South Holland, given the model constraints.

The economic dispatch model will provide insights in the marginal costs of heat production, the utilization of heat sources, storages and infrastructure, and basic system operation (incl.: heat losses and CO_2 emissions). The dispatch model of the district heating system contains the following elements as required by Pusat et al. (2015).

1) *Area specific climatological data*: the model contains a load-duration curve tailored to the daily heat demand pattern for each type of consumer (greenhouse, utility and household) and based on the average outdoor temperature in Rotterdam between 2000-2010. This is further explained in 3.4.2.
2) *Technical specifications*: the model contains estimations for the capacity, costs and heat losses of energy infrastructure, storage and supply technologies, and production constraints for heat sources and heat storages. This is further detailed per system component in 3.4.1-3.4.4.
3) *Cost data*: the model contains a CO_2 price, a heat price, costs of heat production based on utility energy tariffs and production efficiencies and costs of heat storage. This is further detailed per system component in 3.4.1-3.4.4. The model does not contain investment costs, maintenance costs and other fixed costs, such as taxes. For this, a separate model is used. This model is described in chapter 4.
4) *Country specific regulations*: the heat-prices in the model are location specific and the CO_2 content of the heat is included in the heat price. This is in line with the pricing method in the market-design suggested by Programmabureau Warmte Koude Zuid Holland et al. (2015).
5) *Spatial distribution of hourly average energy demands*: the model structure is based on 8 clusters, each representing an area in South Holland. These are further described in 3.2.2. These clusters have location specific supply options. Besides this, each scenario contains consumer and location specific hourly demands.

4.3 SCALE AND SCOPE

The scope of the dispatch model includes all municipalities in South Holland, in which both approaches for developing district heating are a viable option. To establish this list of municipalities, the Province of South Holland was consulted. Because modelling at a municipal level requires more detailed information about infrastructure and the development of demand and supply than is currently available, the municipalities were clustered. The links between the clusters represent the main transport infrastructure in the approach of the PZH. In the approach of the PBL, these links are initially absent. Only when the infrastructure is cost-efficient according to the Vesta/MAIS model, the link is added.

The model consists of eight clusters, each representing a geographical area in the South Holland (figure 25). Six of these clusters contain heat consumers and heat producers, these cluster are Leiden, Lansingerland, Rotterdam North, Rotterdam South, The Hague and Dordrecht. Two cluster, which represent the Rotterdam harbour, only contain heat producers. The six other clusters are named after the central municipality within the cluster. The clusters each consist of 4-9 municipalities located in a range of approximately 10 km from the middle (mathematical centroid, based on outline municipality) of the central municipality. The clustering of the municipalities also occurred in consultation with the PZH.

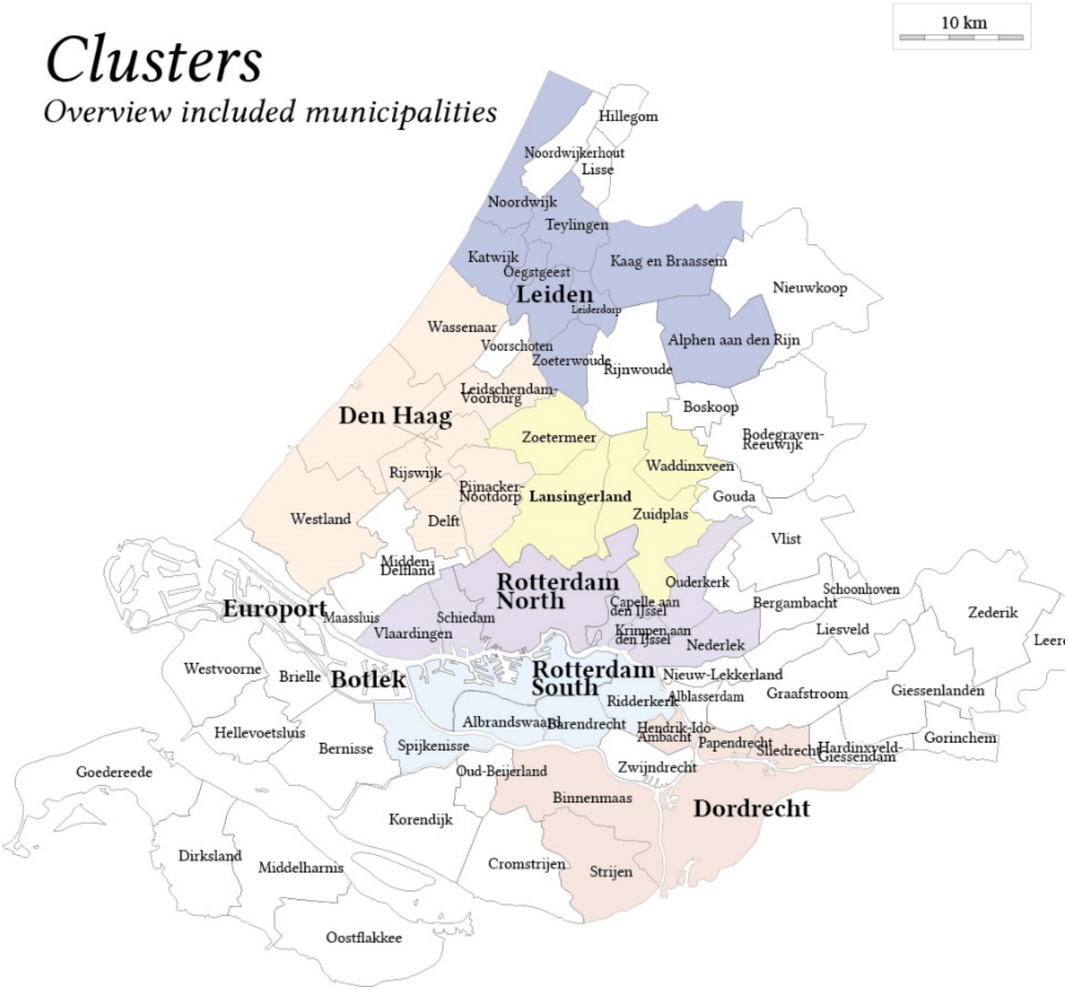


Figure 25 Overview clusters and municipalities

4.4 MODEL DESCRIPTION

The economic dispatch model minimizes the costs of heat supply, given the constraints on demand, production, transport and storage. In this section, the detailed model choices will be discussed for each component of the model (3.3.2-3.3.5). First, a general overview of the model in the software is presented (3.3.1).

4.4.1 MODEL OVERVIEW

Figure 26 shows an overview of the optimization model of a potential district heating system design in South Holland. This is an example of one of the scenarios described in chapter 3. The ovals in the upper left corner report on the overall transport loss and the total CO_2 emissions. The squares each represent a cluster, consisting of heat consumers and producers. The arrows represent a heat transport pipeline and indicate the direction of the flow. Figure 27 shows an example of a cluster within the model. Each cluster has one junction. On this junction, supply and demand are balanced. The top middle shows a heat storage. On the right, the upper process (block) and product (oval) represent the secondary transport and distribution within the cluster and the demand in the cluster. The bottom process is the heat transport between the junction in this cluster and the junction in a neighbouring cluster.

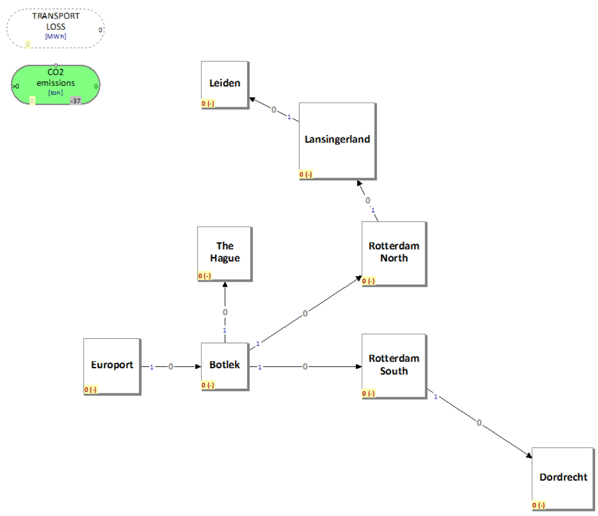


Figure 26 Overview optimization model district heating network South Holland

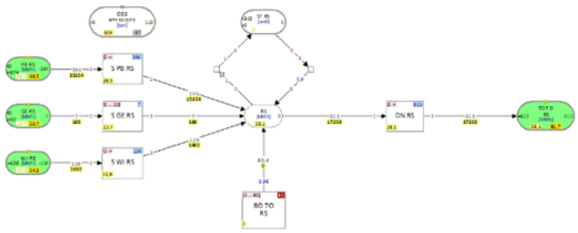


Figure 27 Overview clusters example in Linny-r

The whole of the secondary heat infrastructure and distribution infrastructure, including all connected assets are not modelled explicitly. However, the heat losses that occur in this part of the system are included in the demand. For each time step, the model optimizes the dispatch of heat sources and the utilization of heat storage towards the lowest marginal costs of heat supply. The model meets the two requirements for an open market, discussed in 4.1.9. The dispatch decision is limited by constraints on demand, supply, transport and storage. In section 4.4.1 -4-4.5 the detailed model choices for each of the model components are discussed.

4.4.2 HEAT PRODUCTION

With regard to the heat production, we have made model choices about: available residual heat sources in 2030, the plant characteristics: CO_2 emissions, efficiency and production constraints of heat production plants, and the costs of heat production based on estimated energy and CO2 prices in 2030.

AVAILABLE RESIDUAL HEAT SOURCES IN 2030

South Holland has 25 current and potential residual heat sources (PBL, 2016). Based on the location of the plants, they are divided over the eight clusters. Table 16 shows the available plants per cluster. The current and potential geothermal heat sources are not included in this list. As discussed in chapter 3, both approaches have a particular idea about the development of geothermal heat sources. These ideas will be included in the model runs.

Table 16 Potential residual heat sources on South Holland

#	Name	Type	Capacity (MWth)	Cluster
1	Dordrecht	Waste incinerator	113	Dordrecht
2	Rotterdam	Waste incinerator	126	Rotterdam South
3	Rozenburg	Waste incinerator	387	Botlek
4	Boterdorp	Gas engine	5	Lansingerland
5	OosterHeem	Gas engine	5	Lansingerland
6	Oostpolder	Gas engine	5	Rotterdam South
7	Vaanpark	Gas engine	5	Rotterdam South
8	Wateringseveld	Gas engine	5	The Hague
9	WKC Ypenburg	Gas engine	10	The Hague
10	BP	Industrial residual heat	125	Botlek
11	Esso	Industrial residual heat	125	Botlek
12	Koch	Industrial residual heat	125	Botlek
13	Kuwait	Industrial residual heat	125	Europort
14	Shell	Industrial residual heat	125	Botlek
15	EON-MPP-3	Coal fired plant	698	Europort
16	GDF Suez NL-Maasvlakte	Coal fired plant	480	Europort
17	Den Haag-15	Gas fired plant	76	The Hague
18	Enecogen-2 Dong	Gas fired plant	219	Europort
19	Leiden-12	Gas fired plant	83	Leiden
20	Maasstroom Energie	Gas fired plant	247	Botlek
21	Rijnmond Energie-1	Gas fired plant	235	Botlek
22	Rijnmond Energie-2	Gas fired plant	235	Botlek
23	Roca-1	Gas fired plant	70	Rotterdam North
24	Roca-2	Gas fired plant	70	Rotterdam North
25	Roca-3	Gas fired plant	200	Rotterdam North
Total			**3899**	

PLANT CHARACTERISTICS

Each plant has a value for the marginal costs of heat production and each plant has a value for the CO_2 emissions resulting from this heat production. De marginal costs for heat production and the CO_2 emissions are adopted from the PBL in the year 2030 (PBL, 2016). Table 17 shows an overview of the marginal costs for heat production and CO_2 emissions. The coloured rows indicate which plants have the same characteristics. In the Linny-r model, these plants are represented as one type of plant. The ramping constraints are formulated as a percentage of the total thermal capacity of the plant. They are based on the ramping rates of the heat generation capacity described by Romanchenko et al. (2017).

Table 17 Marginal costs, CO_2 emissions and ramping constraints per type of heat source (CE Delft, 2016; PBL, 2016; Romanchenko, Odenberger, Göransson, & Johnsson, 2017)

Abbreviation	Type of plant	Marginal costs formula	Key figure CO_2 emissions ton/MWh	Ramping constraint
RO	Industrial residual heat	-	0	50%
N	Nuclear	-	0	-
G	Geothermal heat	-	0	-
BCC	Biomass combined cycle plant	$MC_{BCC} = \frac{P_B}{\eta_e} - P_e * \frac{\eta_e}{\eta_{th}}$	0,0666	70%
BT	Biomass turbine	$MC_{BT} = \frac{P_B * 0,2}{0,3}$	0,0666	70%
BC	Small CHP	$MC_{BC} = \frac{P_G}{\eta_e} - P_e * \frac{\eta_e}{\eta_{th}}$	0,2521	70%
WI	Waste Incinerator	$MC_{PB} = P_e * 0,18$	0,0666	70%
CCC	Coal fired plant	$MC_{CCC} = \frac{P_C * 0,2}{0,3}$	0,0666	20%
GCC	Gas fired plant	$MC_{GCC} = \frac{P_G * 0,2}{0,3}$	0,0408	70%
PB	Peak boiler	$MC_{BP} = \frac{P_G}{0,9}$	0,197	100%
GE	Gas engine	$MC_{GE} = \frac{P_G}{\eta_e} - P_e * \frac{\eta_e}{\eta_{th}}$	0,2521	50%

COSTS OF HEAT PRODUCTION

For each type of plant, the marginal costs of heat production are calculated based on the expected energy prices in 2030 incl. transport and distribution costs of the fuel, the SDE-surcharge and energy tax (CE Delft, 2016) . Table 18 shows the overview of the expected energy prices in 2030.

Table 18 Energy and CO_2 prices 2030

Product	Price	
Natural gas	€ 31,20*	€/MW
Coal	€ 8,67	€/MW
Biomass	€ 19,97	€/MW
Green gas	€ 31,20**	€/MW
Electricity	€ 124,00	€/MW
Heat	€81,78 ***	€/MW
CO_2	€ 37,00	€/ton

* based on the electricity price for large consumers (>10 billion kWh/year) in Vesta
** based on the gas price for large consumers (>1 billion m3/year) in Vesta
*** Dutch regulated heat price, 2017

Table 19 shows the marginal costs of heat production including the additional costs for CO_2 emissions. The CO_2 costs at a price of € 37,00 /ton do not affect the merit order.

Table 19 Marginal costs of heat production and CO_2 costs

	Marginal costs of heat production (€/MWh)	CO_2 cost	Total cost of heat
Residual heat: Other industry	€ 0,00	€ 0,00	€ 0,00
Residual heat: Chemical industry	€ 0,00	€ 0,00	€ 0,00
Residual heat: Bio-based industry	€ 0,00	€ 0,00	€ 0,00
Residual heat: Oil refinery	€ 0,00	€ 0,00	€ 0,00
Nuclear	€ 0,00	€ 0,00	€ 0,00
Geothermal heat	€ 0,00	€ 0,00	€ 0,00
Biomass combined cycle plant	€ 5,63	€ 2,46	€ 8,09
Biomass turbine	€ 5,77	€ 2,46	€ 8,23
Waste Incinerator	€ 14,94	€ 2,46	€ 17,40
Coal fired electricity plant	€ 14,94	€ 2,46	€ 17,40
Coal combined cycle plant	€ 14,94	€ 2,46	€ 17,40
Gas combined cycle plant	€ 23,11	€ 1,51	€ 24,62
Gasturbine	€ 23,11	€ 1,51	€ 24,62
Gas fired electricity plant	€ 23,11	€ 1,51	€ 24,62
Gas engine/ Small CHP	€ 23,68	€ 9,33	€ 33,01
Peak boiler	€ 38,51	€ 7,29	€ 45,80

4.4.3 HEAT DEMAND

With regard to the heat demand, we have made model choices about the division of heat consumers into three groups: utility buildings, greenhouses and households, the total demand per consumer group in 2030 and the demand pattern per consumer group. Additionally, we have decided to model the heat losses in the secondary network and distribution network as part of the heat consumption.

THREE CONSUMER GROUPS

Greenhouses, utility buildings and households have different heating behaviour and therefore a different demand pattern. In South Holland, households currently hold 46% of the demand for heat, utility buildings hold 17% of the demand and greenhouses hold 37% of the demand (figure 28). All three consumer groups have an impact on the overall variation in the heat demand. Table 20 shows the total heat demand per cluster per consumer group and the total heat demand per cluster. The heat demand in the clusters Lansingerland and The Hague is dominated by the heat demand in the greenhouse sector. In the other clusters, households are the dominant consumer group. The Hague has by far the largest heat demand. This is because the area of The Hague is both densely populated, and is home to the Westland municipality, which hosts many greenhouse companies. Appendix 1.4 shows the heat demand for each individual municipality within each cluster in PJ for households, utility buildings and households, (excluding heat losses).

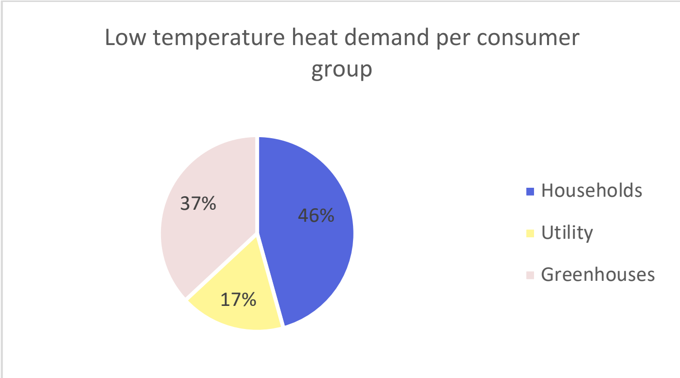


Figure 28 Heat demand per cluster per consumer group in PJ

Table 20 Low temperature heat demand per consumer group (PJ) (Vesta output 2010, South Holland)

	Utility	Greenhouses	Households	Sum
Leiden	2,6	1,6	7,1	11,3
Lansingerland	1,1	9,8	3,9	14,8
Rotterdam North	1,2	0	3,9	5,1
Dordrecht	1,1	0,5	3,9	5,5
Rotterdam South	5,2	1,3	11,8	18,3
The Hague	6,6	25,2	14	45,8

DEMAND PATTERN GREENHOUSES

The desired temperature for greenhouses depends on the type of crops in the greenhouse. The temperature inside a greenhouse depends strongly on the solar radiation. Therefore, degree-hours are not a suitable method for estimating the hourly demand of greenhouses. The eRisk Group provided a file with actual hourly heat demand patterns of 14 different greenhouses in South Holland. This data clearly shows that the heat demand of greenhouses is lower around noon than during the morning and afternoon. To derive a ''standard'' heating pattern for greenhouse, the heat demand of the 14 greenhouses was normalized. This results in the hourly heat demand as shown in figure 29. The figure also shows a trend-line. This line clearly shows that the average hourly heat demand during summer is much lower than the hourly heat demand during winter. During winter, the variations in heat demand are larger than during summer. In winter, the solar radiation has a relatively large impact on the temperature in the greenhouse. However, due to low outdoor temperatures, the temperature in the greenhouse can also quickly drop. This causes large variations in heat demand.

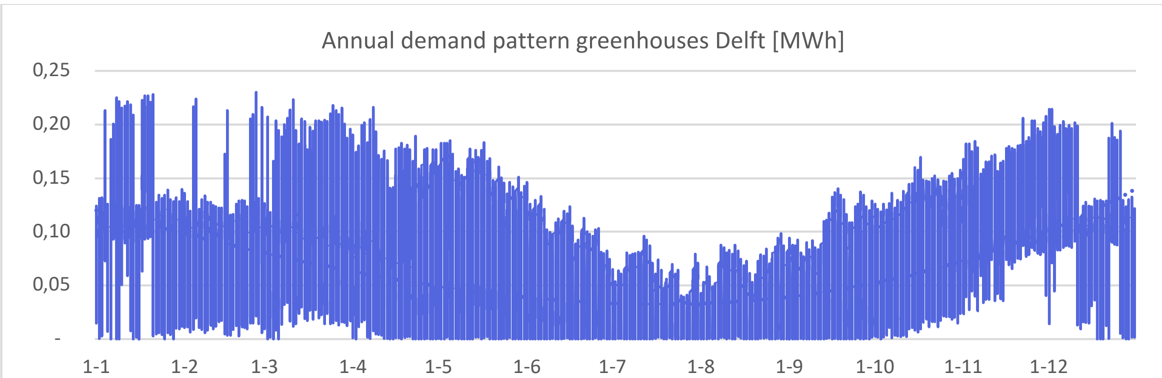


Figure 29 Demand pattern greenhouses

DEMAND PATTERN UTILITY BUILDINGS AND HOUSEHOLDS

For utility buildings and households, only annual demand figures are available, at the level of neighbourhoods. These demand figures can be derived from the Vesta/MAIS model. Variable degree days and variable degree hours are a common method used to estimate the heat demand for buildings when only the annual demand figures are known (Durmayaz, Kadoğlu, & En, 2000; Verbai, Lakatos, & Kalmár, 2014). To identify hourly demand patterns for households and utility buildings in South Holland, the following information is used:

1. Hourly temperature in Rotterdam 2001-2010 (KWA bedrijfsadviseurs, 2017)
2. Daily demand pattern for households and utility buildings
3. Annual demand per neighbourhood

Heat demand patterns for households vary between different types of households, the selected demand pattern is the most common demand pattern in The Netherlands (Ministerie van VROM, 2009). Heat demand patterns for utility buildings also vary per type of building and purpose of the building. The largest categories of utility buildings are industrial/company halls, shops and offices. The assumption is made that these buildings are used between 7 a.m. and 7 p.m. During these hours, the buildings are heated to 19 degrees Celsius. Between 7 p.m. and 7 a.m., the desired indoor temperature drops to 13 degrees Celsius. Table 21 shows the heating patterns for utility buildings and households.

Table 21 Heating pattern households and utility buildings (Ministerie van VROM, 2009)

	Night	Day-time	Evening
Households	16 °C (9 p.m. to 6 a.m.)	19 °C (6 a.m. to 4 p.m.)	20 °C (4 p.m. to 9 p.m.)
Utility buildings	13 °C	19 °C (7 a.m. to 7 p.m.)	13 °C

There is a minimum hot water demand throughout the year. There is no data available on the share of demand for space heating and for the hot tap water demand in district heating networks in The Netherlands. Therefore the assumption is made that the hourly hot-water demand is constant an equal to 20% of the average heat demand.

HEAT LOSSES IN THE SECONDARY NETWORK AND DISTRIBUTION NETWORK

The heat losses in the secondary network and distribution network are included in the demand pattern. For the thermal loss in the secondary infrastructure and distribution network, the following assumptions are made:

1) If the demand is 70%-100% of the network capacity, the thermal loss is 5%
2) If the demand is 40-70% of the network capacity, the thermal loss is 10%
3) If the demand is 20%-40% of the network capacity, the thermal loss is 15%
4) If the demand is 0%-20% of the network capacity, the thermal loss is 20%

Table 22 shows the resulting average heat loss per cluster. These thermal losses are in line with the 15% average thermal loss found by the International Energy Agency (International Energy Agency, 2013).

Table 22 Heat loss per cluster

Cluster	Leiden	Lansingerland	Rotterdam North	Dordrecht	Rotterdam South	The Hague
Thermal loss	15%	20%	10%	15%	17%	15%

The above described assumptions result in the load-duration curve in figure 30 and the normalized average demand pattern in figure 31. This load-duration curve includes all low-temperature heat consumers in South Holland. This load-duration curve resembles a load-duration curves used in a study of Sweden (Marbe, Harvey, & Berntsson, 2006), however differs strongly load duration curves used in a study in Denmark (Pirouti, Bagdanavicius, Ekanayake, Wu, & Jenkins, 2013) and South Wales, UK (Thomsen & Overbye, 2016). It is therefore difficult to determine whether this load-duration curve is valid. The normalized daily demand patterns however does resemble the patterns described in literature (Gadd & Werner, 2015; Pavi et al., 2017).

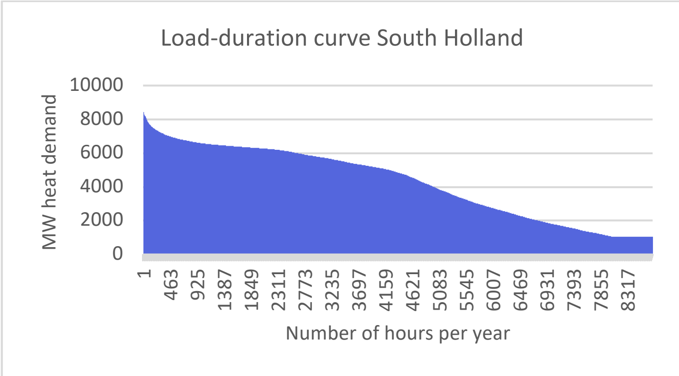


Figure 30 Load-duration curve for all low-temperature heat demand in South Holland in 2030

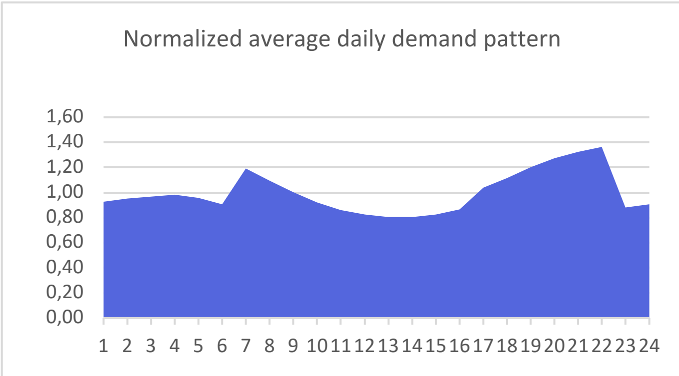


Figure 31 Normalized average daily demand pattern

4.4.4 HEAT TRANSPORT

With regard to the heat transport, we have made model choices about the route and capacity of the pipelines, the thermal losses and pump energy and the flow speed.

ROUTE AND CAPACITY

The route of the main heat transport infrastructure depends on the approach selected for developing the heat infrastructure. This can either be the approach of the PBL or the approach of the PZH. The capacity of heat transport pipelines should be large enough to ensure that here is locally sufficient heat available to supply the base-load. *"'Baseload' is, as the term implies, the part of the load that is constant during the largest part of the year."* (Thomsen & Overbye, 2016, p. 151). Based on a visual fit with the load-duration curve, the size of the pipelines should be at least sufficient to complement locally available base-load plant to supply 60% of the peak demand. Each heat transport pipeline is modelled as a process between two clusters. The length of a transport pipeline is estimated based on the absolute distance between two clusters, times a detour factor of 1.5 (Rooijers et al., 2002).

THERMAL LOSSES & PUMP ENERGY

Pump energy and thermal losses are the main contributors to the variable costs due to network operation. The pump energy is not included in the economic dispatch decision, as Linny-r does not allow for modelling the pressure level and flow speeds. For the same reason, the thermal losses are estimated as a percentage of the flow. The thermal losses in heat transport pipelines are lower than those in de secondary network and distribution network. This is the result of larger pipeline diameters. The province of South Holland expects the heat loss in the transport network will be approximately 4% per transport pipeline. Therefore, a heat loss of 4% of the flow is modelled.

FLOW SPEED AND TIME DELAY

The flow speed of the water and resulting time delay between production and consumption are disregarded. The heat is transported from one cluster to another cluster instantaneously. In reality, district heating networks are slow. The model assumes perfect scenario.

4.4.5 HEAT STORAGE

The capacity of the heat storage is modelled after the average relative daily variation in the demand pattern. The capacity of the heat storage is modelled at 4,2% of the average daily demand. This is relatively small compared to the storage capacities found by Gadd and Werner (2013). In Linny-r heat storage can be modelled as a product. There is a process representing the flow into the storage and a process representing the flow out of the storage. Besides this, a fee for heat storage per time step can be included. The fee for heat storage is estimated at 1 euro/MW per hour storage. The efficiency of the heat storage in Linny-r is modelled at 95%. The storage is meant for hourly variations. The model uses a forward look-up of 6 time steps for optimizing the heat storage. This means that the model optimizes over 7 time steps.

4.5 VERIFICATION, VALIDATION AND SENSITIVITY ANALYSIS

We have performed a model verification (4.4.1) to check if the model does what it is intended to do. Secondly, we have performed a model validation (4.4.1) to check if the model build right and fits the intended purpose. Finally, we have performed a sensitivity analysis (4.4.3) to see for which of the model inputs the model output is sensitive.

4.5.1 VERIFICATION

The model verification is aimed at making sure the model does what it is intended to do. The model should optimize the heat production towards the lowest marginal costs, while optimizing the use of heat storage over 6 time steps and respecting boundaries on: production, demand, transport and storage. The model verification is aimed at testing if the model indeed does this. Table 23 shows the conducted verification tests. We have performed the model-verification tests on each of the modelled scenarios in chapter 6. Detailed model results can be found in Appendix 6. The model behaves as expected and is therefore verified.

Table 23 Tests model verification

Test	Objective	Check
Feasibility of constraints	To check if the model can be solved for each time step.	The model satisfies the demand for each time-step without violating the constraints.
Energy balance	To check if all heat produced can be accounted for in the right way: 1. Consumption 2. Transport loss 3. Storage loss 4. Storage	The energy balance in A.6.1 shows that all heat produced can be accounted for in the right way.
Model logic	To test if the model components interact correctly with each other.	Detailed data analysis, at the level of the dispatch decision per hour, shows that the model satisfies the heat demand for each consumer with the lowest marginal cost plants, given the physical constraints on demand, production, transport and storage and economic data on the marginal costs of heat production, the costs of heat losses and the costs of CO_2 emissions

4.5.2 VALIDATION

The validation concerns the question whether model was build right and fits the intended purpose (van Dam et al., 2013). Four possible ways of validation are: (1) Historic replay, (2) Face validation through expert consultation, (3) Literature validation and (4) Model replication (van Dam et al., 2013). For this model, face validation through expert consultation and literature validation were applied. These are the only two validation methods available for this model.

To validate the model an expert review was performed with a heat expert at HVC group. In general, the model represents a district heating network in a simplified manner. The main takeaways from this model validation step are:

1. The way the heat loss in the transport network is calculated is ok for this limited number of pipelines, but the number of pipelines cannot be increased unlimitedly.
2. The marginal costs of heat production strongly depend on the gas market, the coal market, the market for biomass and subsidies and other tariff regulation. This makes it difficult to predict the marginal costs of heat production. Moreover, heat markets are imperfect and prices often lie higher.
3. Actual load-duration curve usually have a peak-load of 20% of the total demand, and a base-load of 80% of the demand. This load duration curve has a different shape.
4. The storage capacities seem high. It could be that the network can also fulfil a buffer function. This is especially relevant for large networks.

Point 1 and 2 do not directly point to validity issues of the model in the context of the research. However, they show that there are uncertainties and limitations with regard to the generalizability of the modelling approach. Point 3 and 4 may point to a validity issue. These potential issues were further explored as described below:

POINT 3: THE SHAPE OF THE LOAD-DURATION CURVE

The capacity of the transport-pipelines in the model is scaled to the peak-demand in the load-duration curve. The absence of high peak demands is the result of the applied method for estimating the hourly variations in the demand, which is based on average temperatures and as such, levels out peak demands. Besides this, the large share of the heat demand by greenhouses can potentially explain the relatively high "shoulder load", as there are no greenhouse as consumers in the networks of HVC, and greenhouses have a different demand pattern.

The absence of extreme peak demands affects the pipeline capacities in the model design. It is therefore necessary to check what the effect of a differently shaped load-duration curve is on the model design and performance. Appendix 4.1 shows the effect of applying a single reference year to estimate load-variations and the resulting changes in model structure and outcomes. This new load-duration curve shows peak demands that are up to 30% higher and requires pipeline capacities up to 2,5 times the capacities estimated based on used initial load-duration curve. The model design, especially the pipeline capacities are very sensitive to the peak demand. However, the effect on the model outcome, in terms of CO_2 emissions is limited, the CO_2 emissions in the model with the alternative load-duration curve and corresponding pipelines, are 1,5% percentage point lower. In hindsight, it would have been better to use a single reference year to estimate load-variations.

POINT 4: SIZE OF STORAGE CAPACITIES AND THE BUFFER FUNCTION NETWORK

The sizing of the different system-components is based on methods described in literature. However, these methods often limit themselves to smaller district heating networks and the methods have not been evaluated in relation to each other in the context of a more complex dispatch model. The interplay of transport, storage, peak boilers and multiple base-load plants in larger and more complex district heating networks asks for optimization of the components in relation to each other.

Related to this, the model has perfect scenario over seven time steps and the model can instantaneously increase or decrease supply to match the demand. While in reality, there are only demand-expectations. In addition, due to time-delays locally available heat sources, like peak-boilers and storages play a role in matching demand and supply to overcome inconsistencies between demand-expectations and actual demands. This means that there is a discrepancy between the required size of these components in the model and in reality. This indicates that improvements can be made with regard to the sizing of storage, peak-boilers and transport infrastructure, given the connected nature of the designed system. However, this optimization lies outside the scope of this research.

4.5.3 SENSITIVITY ANALYSIS

A sensitivity analysis is performed to identify which of the model inputs have a large effect on the model outcome. The selected model outcome is the total CO_2 emissions from district heating. Appendix 3 contains the results of the performed sensitivity analysis. In this section the main outcomes are discussed. Table 24 shows that the total CO_2 emissions resulting from district heating network operation are sensitive to the local balance between demand and supply. The CO_2 emissions increase or decrease with up to 4,7% as a result of changes in the demand of supply within a cluster of 10%. This is particularly important for the available geothermal heat within each cluster, as the estimations for this input strongly vary between the approaches. The sensitivity analysis shows that an increase in the overall availability of geothermal heat of 10%, results in 3,7% increase or decrease in CO_2 emissions. The CO_2 emissions from network operation are less sensitive to the general capacity of the heat infrastructure. When we add-up the results of the sensitivity analysis, and we assume that the uncertainty range on each of these model inputs is actually 10%, the uncertainty range on the output lies between -25,3% and +25,4%[1]. This means that the actual CO_2 emissions from district heating can strongly deviate depending on the final system design.

Table 24 Output sensitivity analysis – CO_2 emissions

Input	Min 10%	Normal input	Plus 10%
Pipeline capacity	1,4%	0,0%	-1,4%
Transport loss	0,0%	0,0%	0,0%
Storage capacity	0,0%	0,0%	0,0%
Storage loss	0,0%	0,0%	0,0%
Capacity plants Europort	0,0%	0,0%	0,0%
Capacity plants Botlek	0,0%	0,0%	0,0%
Capacity plants Rotterdam South	0,4%	0,0%	-0,4%
Capacity plants Rotterdam North	0,0%	0,0%	0,0%
Capacity plants Dordrecht	0,3%	0,0%	-0,3%
Capacity plants Lansingerland	1,7%	0,0%	-1,7%
Capacity plants Leiden	1,9%	0,0%	-1,9%
Capacity plants The Hague	0,3%	0,0%	-0,3%
Geothermal heat	3,7%	0,0%	-3,7%
Demand Rotterdam South	-2,4%	0,0%	2,5%
Demand Rotterdam North	-0,4%	0,0%	0,4%
Demand Dordrecht	-0,7%	0,0%	0,7%
Demand Lansingerland	-4,4%	0,0%	4,4%
Demand Leiden	-4,7%	0,0%	4,7%
Demand The Hague	-3,0%	0,0%	3,0%

The results of the sensitivity analysis also show, that in clusters with a relatively large availability of local base-load plants like Dordrecht and Rotterdam North, the CO_2 emissions in the cluster do not strongly increase or decrease when the demand changes (<1%). The small increases in the demand can almost completely be solved by additional heat imports or additional local production through base-load plants. In clusters where there is a relatively low local availability of base-load plants, like Leiden and Lansingerland, the CO_2 emissions do increase when the demand increases. In these clusters, an increase in the demand means that plants that have relatively high emissions (like the peak-load plants) need to supply more heat.

4.6 COMPARISON OF INPUT DATA

The sensitivity analysis in 4.4 shows that the model output is sensitive to the datasets that describe the demand and supply in 2030. Both of the datasets used in the model, stem from the PBL. In this section, we will compare the data with available data from CE Delft, Port of Rotterdam and Gasunie that describe their forecasts for heat demand and supply towards 2030. We make this comparison to see how uncertain these sensitive model inputs are.

4.6.1 AVAILABILITY OF RESIDUAL HEAT

The dataset used for the availability of residual heat sources and their thermal capacity is the dataset was developed by PBL in 2009 for the Vesta/MAIS model. It contains a list of existing electricity plants and potential other industrial heat sources. PBL estimated the availability of (residual) heat for district heating based on the type of plant, the electrical capacity of the plant and the electrical efficiency of the plant. The original dataset shows that only a limited number of thermal capacities could be verified. The data is compared to two dataset: 1) The dataset of CE Delft, which shows two prognosis for the development of heat for district heating in South Holland towards 2030 and 2) the dataset

[1] In this summation, we have not accounted for the interaction between the different model inputs (for example increased demand and declined available capacity). Interactions between these inputs could result in even more extreme changes in the CO_2 emissions.

of the Port of Rotterdam and Gasunie, which shows the expected available heat in the Rotterdam harbour towards 2050.

Table 25 shows an overview of the total available supply per type of heat source in each of the datasets. CE Delft estimated the thermal potential from residual heat sources based on the location and CO_2 emissions of industrial complexes in South Holland. All industrial process with a known energy demand larger than 400 TJ were included in the analysis. The assumption is made that these industries run at full capacity 90% of the year. Moreover, per industry a percentage of the energy demand is defined, which represents the potential for residual heat supply. These percentages vary between 60% for waste-to-energy plants and 10% for oil refineries.

It is unknown how PoR/Gasunie estimated the availability of heat in the Rotterdam harbour. Compared to the dataset of CE Delft, and Port of Rotterdam and Gasunie, PBL estimates a relatively low availability of geothermal heat and residual heat from industry and a relatively high availability of residual heat from the electricity sector, including waste incinerators. On the other hand, the PBL estimates a very high availability of residual heat from the electricity sector, including the electricity plants that are currently coal-based. The energy transition is slowly moving the Dutch electricity system from fossil fuel based to renewables based, which will affect the availability of residual heat from this sector. This is not reflected in the dataset of the PBL. The total estimates of PBL are in the same range as the expectations of CE Delft. However, the range of available heat supply is very large. In comparison to the PBL, the estimations of CE Delft vary between +37% and -28%. The Port of Rotterdam and Gasunie expect a lower total availability of heat, but they only consider the Rotterdam harbour. These institutes expect between 20% and 78% lower availability of residual heat.

Table 25 Comparison of total available supply

Organization	**PBL**	**CE Delft**	**CE Delft**	**PoR/Gasunie**	**PoR/Gasunie**	**PoR/Gasunie**	
Scenario	Reference	High	Low	High	Medium	Low	
Gas engine	35	-	-	-	-	-	MW
Gas fired plant	1435	-	-	-	-	-	MW
Coal fired plant	1178	-	-	-	-	-	MW
Small CHP	13	-	-	-	-	-	MW
Electricity sector	2661	1632	816	-	-	-	MW
Geothermal heat	49	600	288	504	361	136	MW
Waste-to-heat	556	381	191	270	270	238	MW
Residual heat: Oil refinery	625	1619	809	1332	555	270	MW
Residual heat: Bio based industry	-	-	-	396	203	63	MW
Residual heat: Chemical industry	-	724	362	320	251	82	MW
Residual heat: Other industry	-	110	55	279	178	76	MW
Residual heat	625	2453	1226	2327	1187	491	MW
Total Rotterdam harbour	-	5066	2521	3101	1818	865	MW
Total other locations	-	263	263	-	-	-	
Total	3891	5329	2784	3101	1818	865	MW
% deviation		+37%	-28%	-20%	-53%	-78%	

4.6.2 DEMAND

The dataset used for the availability of residual heat sources and their thermal capacity is the dataset that is developed in Vesta/MAIS model, to describe the heat demand in 2030. This dataset is compared to the demand data computed by CE Delft for 2030 (table 25). The following five main differences were found:

1. The total heat demand calculated by CE Delft for houses and utility buildings in South Holland in 2015 is approximately 115 PJ. While Vesta/MAIS a little over 120 PJ is calculated, so the initial conditions for calculating the development of the heat demand are slightly different.
2. In the dataset of the CE Delft, the development of the demand solely depends on a reduction factor of 2% per year. This reduction factor results in a reduction of the heat demand of 50% by 2050. This is in line with the expectation of the Province of South Holland. However, Vesta/MAIS shows no indications of such a drastic decline in the heat demand. Under the used model setting, the insulation rate is nil.

3. In the Vesta/MAIS data, the heat demand from greenhouses in included in the total heat demand. In the data of CE Delft the heat demand from greenhouses is mentioned separate, as the demand in the ‘’Oostland’’ and the demand in the ‘’Westland’’. Moreover, CE Delft does not specify the heat demand in each municipality, which makes it difficult to compare the data at the level of the specified clusters.
4. The linear heat density determines the economic feasibility of the operation of a district heating network. CE Delft performed an analysis on the density of the heat demand in the municipalities in South Holland in 2015. When the density of the heat demand is larger than 500 GJ per acre, the neighbourhood is considered suitable for connecting to a DH network according to CE Delft. This lower than the 140-180 MJ/m² mentioned by Frederiksen and Werner (2013). In the analysis of CE Delft, 65% of the neighbourhoods had a sufficiently high density of heat demand.

At municipal level, the estimations of CE Delft are approximately 73% of the estimations of the Vesta/MAIS model. Possible reasons for these differences are:

1. Different approach for calculating the heat demand per municipality.
2. Different municipal boundaries in CBS data between 2014 (PBL) and 2015 (CE Delft).
3. Exclusion of neighbourhoods with low demand densities by CE Delft.

At the level of the demand clusters, the data for the scenarios for the heat demand in 2030 established for this research can also be compared with the data from the scenarios for the heat demand established by CE Delft. The definition of demand clusters by CE Delft is slightly different from the definition in this research. Moreover, CE Delft did not scale the demand in the greenhouse sector for the demand scenarios.

The comparison in table 26 shows that in this research, the overall heat demand is slightly higher than estimated by CE Delft. Especially in Leiden and Dordrecht the discrepancies are relatively large compared to the total demand. The 80% scenarios show larger differences than the 50% scenarios. This is because the scenarios of CE Delft have a much lower estimation of the heat demand in the greenhouse sector than the Vesta/MAIS model has calculated. The heat demand per cluster calculated for this research is on average slightly higher for the 50% scenario and much higher for the 80% scenario. This has two main causes:

1) Different demand per municipality (lower in CE Delft estimates).
2) Differences between included and excluded municipalities for each cluster (different scope)
3) Different calculation and allocation of heat demand in the greenhouse sector.

These differences result in a relatively high heat demand in Dordrecht, Leiden and Rotterdam. In general the heat demand lies within the same magnitude of the demand data estimated by CE Delft. Moreover, differences in demand can be explained by the approach used for calculating the heat demand.

Table 26 Heat demand in 2030: comparison of Vesta/MAIS output and CE Delft data

<table>
<tr><th></th><th>CE Delft</th><th></th><th></th><th>PBL</th><th></th></tr>
<tr><th>Cluster</th><th>Low scenario (50%)</th><th>High scenario (80%)</th><th>Cluster</th><th>50% total demand</th><th>80% total demand</th></tr>
<tr><td>The Hague and surroundings</td><td>7,42</td><td>11,41</td><td rowspan="3">The Hague</td><td rowspan="3">27,1</td><td rowspan="3">43,3</td></tr>
<tr><td>Westland</td><td>20,70</td><td>21,11</td></tr>
<tr><td></td><td>28,12</td><td>32.52</td></tr>
<tr><td>Drechtsteden</td><td>1,10</td><td>1,63</td><td>Dordrecht</td><td>3,3</td><td>5,2</td></tr>
<tr><td>Leiden and surroundings</td><td>2,16</td><td>2,98</td><td>Leiden</td><td>6,7</td><td>10,7</td></tr>
<tr><td>Oostland</td><td>8,89</td><td>9,23</td><td rowspan="4">Lansingerland</td><td rowspan="4">8,4</td><td rowspan="4">13,5</td></tr>
<tr><td>Zoetermeer</td><td>0,89</td><td>1,42</td></tr>
<tr><td>Gouda and surroundings</td><td>1,25</td><td>1,62</td></tr>
<tr><td></td><td>11,03</td><td>12,27</td></tr>
<tr><td rowspan="2">Rotterdam and surroundings</td><td rowspan="2">10,51</td><td rowspan="2">15,02</td><td>Rotterdam North</td><td>2,9</td><td>4,6</td></tr>
<tr><td>Rotterdam South</td><td>10,9</td><td>17,5</td></tr>
<tr><td></td><td></td><td></td><td></td><td>13,8</td><td>22,1</td></tr>
<tr><td>Total</td><td>52,91 PJ</td><td>64,41 PJ</td><td></td><td>59,2 PJ</td><td>94,7 PJ</td></tr>
</table>

4.7 DISCUSSION AND CONCLUSION

In this chapter, we have started with a conceptual description of district heating systems. Secondly, based on this conceptual description an economic dispatch model for a large district heating network was developed. This model can calculate the optimal hourly dispatch schedule, based on the marginal costs of heat production and transport, given the constraints on demand, supply, production and storage. This model was verified and validated. However, the model validation has pointed out that:

1) the development of energy and CO_2 prices towards 2030 are highly uncertain and,
2) the shape-of the load-duration curve is a-typical for Dutch households.

We have seen that the merit order is not sensitive to the CO_2 price. Moreover, we have performed a model run with an alternatively shaped load-duration curve. This exercise shows that the design of the system is very sensitive to the shape of the load-duration curve.

Moreover, we have performed a sensitivity analysis in which we checked the effect of the model inputs on the CO_2 emissions. The sensitivity analysis has pointed out that the model is sensitive to the development of the heat demand over time, which depends on insulation, demolition and construction, demographic changes etc. and the development of the availability of residual heat sources over time. Therefore, we have looked into differences between datasets that can be used as inputs for the dispatch model. The used data sets of the PBL, were compared with datasets of CE Delft, Gasunie and Port of Rotterdam. These alternative datasets show other estimations for both the development of the heat demand and the availability of residual heat in South Holland in 2030. These datasets show that if the estimations of Gasunie and PoR are correct, the feasibility of the 50% scenarios of the PZH depends on the development of geothermal heat sources.

This indicates that the development of the heat demand and the development of available heat sources are uncertain. Main limitations of the model are, the uncertainty with regard to the shape of the load-duration curve, uncertainty with regard to the data-inputs (total demand and supply) and the lack of time-delays in the network.

5.

Description of a cost-model for district heating networks

In chapter 4, we have developed an economic dispatch model. However, as described in chapter 2, we are also interested in gaining insights in the investment costs and the effects of uncertainties in the transition approaches on these investment costs. The objective of this chapter is to develop a model, which is capable of calculating the investment costs and fixed costs of a district heating system design, based on the available data and the model requirements. 5.1 contains the model requirements, which are derived from the system description in 4.1. Section 5.2 contains the high-level model choices and in 5.3 all model functions are described. In 5.4 the model is verified and validated. Moreover, in 5.4 the model limitations are discussed. Section 5.5 contains a discussion and conclusion of the model fitness for purpose.

5.1 Model requirements

The cost model should accurately estimate the investment costs and fixed costs for different system designs and network topologies. Moreover, the costs model should be able to report on investment costs, fixed costs, variable costs, annual returns and CO_2 emissions of heat production. The calculation of the investment costs and fixed costs should be scalable, in the sense that the model should be able to estimate the investment costs and variable costs for all scenarios within the research, and precise, in the sense that the differences between the scenario designs are reflected in the costs.

Section 4.1 shows that district heating networks consist of the following elements:

1. Base load plant(s)
2. Transport infrastructure
3. Heat stations (incl. peak load plants)
4. Secondary infrastructure and side pipelines of secondary infrastructure
5. Distribution network
6. Substations in distribution networks
7. Heat storage

All of these elements should be included in the model for the investment costs. It is not necessary to develop a model for the investment costs for district heating systems from scratch. The PBL and CE Delft have developed a cost model (CE Delft, 2016). This model covers the first 6 out of the 7 system components. This model is used as a starting point for the development of a model for the investment costs. The model is adapted to fit the available data and implemented in excel. The 7^{th} element for heat storage is added to the model. In this chapter, we will show how we have adapted the model of the PBL and CE Delft.

5.2 HIGH-LEVEL MODEL CHOICES

In chapter 3, we have seen that for both approaches there is high-level data available that describes expectations with regard to demand, supply and infrastructure of district heating systems in South Holland towards 2030. This high-level data describes annual demand and supply figures and general estimations or heuristics for estimating pipeline capacities. The model the PBL and CE delft have developed, requires more detailed data. The model is developed to calculate investment costs and fixed costs based on geographical data, containing specific information about consumer types and land use. To make the model fit for purpose, we need to simplify the cost formulas, without compromising the validity of the model outcome. To guide this process, we have used the insights from the conceptual description of district heating networks in section 4.1 In 5.3 and 5.4 we describe how we did this.

The resulting model is an excel sheet that automatically scales investment costs and fixed costs to the estimated annual heat demand. This automatic scaling occurs for the following cost-components: heat stations, secondary infrastructure, distribution network, substations and heat storages. To use the model, user needs to have information about the average density of the demand in the system, the length and capacity of the primary heat transport infrastructure, the total capacity of geothermal heat sources and the total capacity of residual heat sources. Additionally, the model does not check whether the combination of supply, demand and infrastructure is feasible. This needs to be checked by the user (for example via an evaluation of the base-load and the peak-load).

The cost-model calculates annual costs per system component, and for the system as a whole. Moreover, the model calculates annual returns based on the NMDA price for small heat consumers, and the maximum marginal costs of heat production for large heat consumers. The model reports on the annual costs and returns with overview tables and figures. The model is also connected to the output data of the dispatch model, so that the variable costs of heat production and the CO_2 emissions can be included in the cost analysis. The model has one important limitation. The investment-costs for the main heat infrastructure pipes are only valid for pipelines with a capacity of maximum 115 MW, while the maximum necessary pipeline capacities calculated in chapter 3 lie up to 7,2 times higher.

5.3 MODEL DESCRIPTION

In this section, we will mathematically describe the model for the investment costs and fixed costs. Table 27 shows the used symbols. Table 28 shows the specification of factors. The abbreviations used are explained per system component in 5.3.1-5.3.8.

Table 27 List of symbols

Abbreviation	Unit	Explanation
$\mathbf{IC}$	€	Total investment costs
$\mathbf{IS}$	€/kW	Scalable Investment cost
$\mathbf{P}$	MW	Thermal capacity
$\mathbf{L_{pipe}}$	m	Length of pipeline
$\boldsymbol{\alpha_{de}}$	–	Dimensionless detour factor
$\mathbf{A}$	m^2	Surface
$\boldsymbol{\alpha_{peak}}$	–	Peak loss factor
$\boldsymbol{\alpha_{con}}$	–	Parallel consumption factor
$\mathbf{ceil}(*)$		Ceiling operator
$\mathbf{RC}$	€	Maintenance costs
$\boldsymbol{\alpha_{RC}}$	–	Dimensionless maintenance factor
$\mathbf{PT}$	€/m	Precario tax
$\mathbf{n_{sub}}$	–	Number of substations
$\mathbf{f}$	–	Market share district heating
R	€/year	Revenues
PN	€/MWh	NMDA price
PM	€/MWh	Max. marginal costs of heat production

Table 28 Specification of factors

Factor	Specification
α_{de}	1.25
α_{peak}	0.05
α_{con}	0.7
α_{node}	-
$\alpha_{RC,B,i}$	Table 29
α_{DN}	0.025
$\alpha_{pipe,sec}$	0.01
α_{trans}	0.03
α_{node}	0.03
α_{sub}	0.03
α_{sto}	0.03
α_{u}	0,17
α_{c}	0,46
α_{g}	0,37

5.3.1 HEAT STATION

The investment costs of heat stations are linear scaled with the demand. The maintenance costs are a fraction of the investment costs. It is therefore not necessary to calculate the number of heat stations and peak boilers within each cluster. The investment costs for a heat station, including a peak boiler can be estimated at 125000 €/MW (CE Delft, 2013). The largest cost component for the heat stations are the peak boilers. It is common that peak boilers can supply between 70% and 100% of the total demand in the secondary network connected to the heat station (CE Delft, 2016). To estimate the required investment costs based on the required capacity of the heat station, the required capacity of the heat station is scaled at 85% of the total demand within the network behind the heat station (CE Delft, 2016).

Investment costs heat stations per cluster:

$$IC_{node,i} = 0{,}85 * P_{DN,i} * IS_{node}$$

$$i = [RN, RZ, DO, LL, LEI, DH, HA]$$

Maintenance costs heat station per cluster:

$$RC_{node,i} = IC_{node,i} * \alpha_{node}$$

5.3.2 BASE LOAD PLANTS

The investment costs are equal to the one-time costs of adapting an existing plant so it can be connected to a district heating network. These costs are listed in euro per kW. The annual maintenance costs are equal to a percentage of the investment costs. Table 29 contains an overview of the investment costs per type of plant and the percentage annual maintenance costs.

Investment costs connection of base load plant per cluster per type of plant:

$$IC_{B,k,i} = IS_{B,k,i} * P_{B,k,i}$$

$$k = [RO, RC, RB, RR, N, G, BC, BT, WI, C, CCC, GCC, GT, GP, GE]$$

Maintenance costs connection of base load plant per cluster per type of plant:

$$RC_{B,k,i} = IC_{B,k,i} * \alpha_{RC,B,i}$$

Table 29 Overview investment costs connection base load plant (adopted from: Vesta/MAIS)

Type of plant	Symbol	Inv. costs connection (€/kW)	Maintenance costs (% inv.costs)
		$IC_{B,k,i}$	$\alpha_{RC,B,i}$
Residual heat: Other industry	RO	€ 250.00	5%
Residual heat: Chemical industry	RC	€ 250.00	5%
Residual heat: Bio-based industry	RB	€ 250.00	5%
Residual heat: Oil refinery	RR	€ 250.00	5%
Geothermal heat	G	€ 1,875.00	1%
Small combined cycle plant	BC	€ 875.00	5%
Biomass turbine	BT	€ 167.50	5%
Waste Incinerator	WI	€ 167.50	5%
Coal fired electricity plant	C	€ 167.50	5%
Coal combined cycle plant	CCC	€ 162.50	5%
Gas combined cycle plant	GCC	€ 162.50	1%
Gasturbine	GT	€ 180.00	1%
Gas fired electricity plant	GP	€ 167.50	1%
Gas engine	GE	€ 1,300.00	1%

5.3.3 TRANSPORT INFRASTRUCTURE

Heat transport is the transport of heat from the plant to the heat station. The heat station is the connection between the heat transport infrastructure and the secondary heat network. CE Delft estimated a minimum and a maximum curve for the costs of heat infrastructure. These minimum and maximum curves are valid for pipelines up to 115 MW(CE Delft, 2016). It is unclear how the investment costs change when the pipeline capacities exceed this capacity. In this model the average investment costs for heat transport infrastructure are used. The maintenance costs of the transport infrastructure are estimated as 1% of the investment costs per year (CE Delft, 2016).

Investment costs transport infrastructure:

$$IC_{pipe,trans,min,j} = 212{,}5 * \ P_{pipe,j}{}^{0{,}4828} * L_{pipe,j}$$

$$IC_{pipe,trans,max,j} = 379{,}3 * \ P_{pipe,j}{}^{0{,}4739} * L_{pipe,j}$$

$$IC_{pipe,trans} = \frac{1}{2}\left(IC_{pipe,trans,min} + IC_{pipe,trans,max}\right)$$

$$j = [LALEI, RNLA, BLRN, BLRS, BLDH, RNDO, RNLA]$$

Maintenance costs transport infrastructure:

$$RC_{trans,j} = IC_{trans,j} * \alpha_{trans}$$

5.3.4 SUBSTATIONS

The number of substations depends on the quantity of the heat demand and the type of heat consumers connected to the substation. Because heat consumption patterns of individual consumers can even-out the daily and hourly fluctuations in demand, the capacity of the substation can be smaller than the maximum hourly demand. This correction factor for parallel consumption is 0.5 for households and 0.7 for large utility buildings and 1 for greenhouses (CE Delft, 2016). In the total demand, 37% of the demands is demand for greenhouses and 46% of the demand is the demand for households. Therefore, the average parallel consumption factor is estimated at 0.7. During peak demands the capacity requirement for the substation is higher. To correct for peak demands, the capacity requirement is corrected by 1,1. The standard capacity of a small substation is 825 kW. The investment costs are 82500 €/substation, or 100€/kW (CE Delft, 2016). Large utility buildings and greenhouses, with a connection >3000kW may require individual larger sub-stations. The estimated costs of these large substations are lower than the costs used here 82.5 €/kW (CE Delft, 2016). Since the number of very large connection is unknown for the Province of South Holland, this is not included in the cost model. Therefore, the estimation for the investment costs for the substations is relatively high.

Investment costs substations per cluster:

$$n_{sub,i} = ceil\left(\frac{\frac{1}{1-\alpha_{peak}} * \alpha_{con} * P_{DN,i}}{825}\right)$$

$$IC_{sub,i} = 82500 * n_{sub,i}$$

Maintenance cots substations per cluster:

$$RC_{sub,i} = IC_{sub,i} * \alpha_{sub}$$

5.3.5 SECONDARY INFRASTRUCTURE

The secondary infrastructure runs from the heat station to the substation. The logic for the investment costs of the sub-stations in this model is based on the layout for residential areas, with small substations. For greenhouses and large utility buildings, more side pipelines may be necessary, but their length could be shorter. Moreover, a more complex design for the secondary network for greenhouses may be necessary, where local recirculation would lead to higher securities of demand (CE Delft, 2016). These refinements are not included in this cost model because of the level of detail of the available data. To estimate the required length of the secondary infrastructure, it is necessary to know the surface area of the network and the number of substations in the network. The estimated maximum surface area of the network in each cluster is equal to 314,160 m^2. This is based on an average radius of 10 km. as approximately all municipalities in a radius of 10 km were included in a cluster. To correct for concentration of the demand when the market penetration rate of district heating is below 100%, the estimated surface area is scaled with the market penetration rate of district heating in the cluster:

$$A = \pi r^2 * f$$

$$f_{node,i} = \frac{P_{node,i}}{P_{node,max,i}}$$

The secondary infrastructure consists of main pipelines and side pipelines. The total length of the main pipeline of the secondary infrastructure depends on the total surface area (CE Delft, 2016). The average costs for the secondary heat infrastructure were used.

Investment costs main pipelines secondary network per cluster:

$$IC_{pipe,main,min,i} = 212{,}5 * P_{node,i}{}^{0{,}4828} * L_{pipe,main,i}$$

$$IC_{pipe,main,max,i} = 379{,}3 * P_{node,i}{}^{0{,}4739} * L_{pipe,main,i}$$

$$L_{pipe,main,i} = \alpha_{de}\sqrt{2} * \sqrt{A}$$

$$r = 10000\ m$$

$$\alpha_{de} = 1{,}25$$

$$IC_{pipe,main,i} = \frac{1}{2}(IC_{pipe,main,min,i} + IC_{pipe,main,max,i})$$

The total length of the side pipelines within each cluster depend on the length of the main pipeline of the secondary network and the number of substations (CE Delft, 2016).

Investment costs side pipelines secondary network per cluster:

$$IC_{pipe,side,min,i} = 212{,}5 * \left(\frac{P_{node,i}}{n_{sub,i}}\right)^{0{,}4828} * L_{pipe,side,i}$$

$$IC_{pipe,side,max,i} = 379{,}3 * \left(\frac{P_{node,i}}{n_{sub,i}}\right)^{0{,}4739} * L_{pipe,side,i}$$

$$IC_{pipe,side,i} = \frac{1}{2}\left(IC_{pipe,side,min,i} + IC_{pipe,side,max,i}\right)$$

$$L_{pipe,side,i} = \alpha_{de} * n_{sub,i} * \frac{1}{8}\sqrt{2} * \sqrt{A}$$

Maintenance costs secondary network per cluster:

$$IC_{pipe,sec,i} = \sum_{i} IC_{pipe,main,i} + IC_{pipe,sub,i}$$

$$RC_{pipe,sec,i} = IC_{pipe,sec,i} * \alpha_{pipe,sec}$$

5.3.6 DISTRIBUTION NETWORK

The distribution network is the part of the heat network that supplies heat from a sub station to the building. The assumption is made that each household and utility building requires 15 meters of heat distribution network (CE Delft, 2016). The investment costs of the distribution network are scaled with the capacity of the network. The investment costs are equal to 125 euro/m. The average individual connection is estimated at 11kW (CE Delft, 2016). This is based on the connections for households and small utility buildings, which are the same (CE Delft, 2016). Large utility buildings and greenhouses are not connected to a distribution network, but to a separate side-pipeline of the secondary network. The length and quantity of these networks depends on the surface are for large utility buildings and greenhouses, which are unknown. Therefore, the assumption is made that all demand is connected to the distribution network.

Investment costs distribution network per cluster:

$$IC_{DN,i} = IS_{DN,i} * P_{DN,i}$$

$$IS_{DN,i} = 125\ €/m$$

$$L_{pipe,DN,i} = 15 * \frac{P_{DN,i}}{11}$$

Maintenance costs distribution network per cluster:

$$RC_{sub,i} = IC_{sub,i} * \alpha_{sub}$$

5.3.7 HEAT STORAGE

The Province of South Holland considers thermal energy storage an essential way to make the low-temperature heating system more sustainable (Provincie Zuid Holland, 2016). Figure 31 in chapter 4 shows the normalized average daily demand pattern based on the estimated hourly demand for heat in South Holland. The pattern is similar to the pattern found by Wouters et al. (2015). This figure shows that on an average day, there are two moments of peak demand, one during the morning, around 7:00 and one during the evening, between 18:00 and 22:00. The volume of the largest peak is approximately 4.2% of the daily demand. To compensate the daily load variations, the capacity of the thermal heat storage should thus be approximately 4.2%. Large heat storage tanks are the cheapest method for thermal energy storage (IRENA, 2013).The investment costs of these large heat storage tanks lie around 75 €/kW (IRENA, 2013).

Investment costs heat storage per cluster:

$$IC_{sto,i} = 0.042 * P_{DN,i} * 75$$

Maintenance heat storage per cluster:

$$RC_{sto,i} = IC_{sto,i} * \alpha_{sto}$$

5.3.8 TOTAL ANNUAL INVESTMENT COSTS, MAINTENANCE COSTS AND TAXES

The total annual costs consist of the variable costs, discussed in chapter 3, the investment costs, maintenance costs and precario tax. The investment costs are depreciated over a period of 30 years.

Total investment costs:

$$IC_{tot} = \sum_{k,i} IC_{B,k,i} + IC_{DN,i} + IC_{pipe,main,i} + IC_{pipe,side,i} + IC_{node,i} + IC_{sub,i} + IC_{sto,i} \sum_{j} IC_{pipe,trans,j}$$

$$IC_{year} = \frac{IC_{tot}}{30}$$

Total annual maintenance costs:

$$RC_{tot} = \sum_{k,i} RC_{B,k,i} + RC_{DN,i} + RC_{pipe,sec,i} + RC_{node,i} + RC_{sub,i} + RC_{sto,i} \sum_{j} RC_{pipe,trans,j}$$

Total annual costs precario tax:

$$PT_{tot} = \left(\sum_{i} L_{pipe,DN,i} + \sum_{i} L_{pipe,main,i} + \sum_{i} L_{pipe,side,i} + \sum_{j} L_{pipe,trans,j} \right) * PT$$

$$PT = 4{,}3\ €/m$$

The annual costs are thus:

$$C_{year} = IC_{year} + RC_{tot} + PT_{tot}$$

5.3.9 ANNUAL REVENUES

The annual revenues are the revenues on the heat sales to consumers, utility buildings and greenhouses. For consumers and (small) utilities, the heat price is regulated.

$$R_{c,u,year} = P * (x_u + x_C) * PN$$

$$R_{g,year} = P * x_g * PM$$

$$R_{year} = R_{c,year} + R_{g,year}$$

The NMDA price for heat is €81,68 per kWh. The maximum marginal costs of heat production incl. CO_2 costs, at a price of €37/ton are €41 per kWh.

5.4 VERIFICATION, VALIDATION AND SENSITIVITY ANALYSIS

In this section, the main outcomes of the verification, validation and sensitivity-analysis steps are discussed. Appendix 3 contains an extensive model verification and sensitivity analysis.

5.4.1 VERIFICATION COST-MODEL

The model-verification has led to the identification of three main model limitations. When these limitations are taken into consideration, the model can accurately calculate the investment costs for a district heating network. These model limitations are:

1. All estimations for the lay-out of the secondary infrastructure, distribution network, heat stations and sub-stations are based on the network lay-out which is typical for households. A lack of spatially detailed data on the distribution of demand and types of consumers in the approach of the PZH limits the level of detail at which these estimations can be made for large utility buildings and greenhouses. The expectation is that the actual investment costs will be slightly lower due to the different infrastructure layout in this part of the system.

2. The model does not check the compatibility of the supply and demand, network length, route and capacity of the primary heat transport infrastructure, with the other system component, which are scaled to the annual heat demand. Therefore, it is necessary to check if the design choices with regard to demand, supply and main infrastructure are feasible. For this study, a check was performed on the energy balance under base-load and peak-load conditions within each cluster; this check is described in appendix 5.
3. The model does not check the compatibility of the available heat sources with the (spatial distribution of) the demand. This check needs to be performed externally. This is described in appendix 5.

5.4.2 VALIDATION COST-MODEL

To validate the model an expert review was performed with a heat expert at HVC group. The investment costs calculated by the model are similar to the investment costs of district heating networks of HVC. The main model limitations identified are:

- The calculated investment costs are slightly higher per MW (+10%) than HVC typically would calculate. That the calculation does not include in-house investments and connection fees may explain the relatively high total investment costs.
- The investment costs for connecting a gas-based electricity plant seem high. HVC takes a value in the range of 100€/kWh.
- The investment costs for developing and connecting a geothermal well seem relatively low. Estimates can lie up to 30% higher. However, this strongly depends on the location and type of well and the expected return temperature. The investment costs for geothermal heat is an uncertain number.
- Households and small utility consumers pay the NMDA price for heat. For large consumers the heat price is unregulated. This affects the heat price they pay. For example, greenhouses typically pay approximately 1/4th of the NMDA price. Greenhouses benefit from the low gas prices for large consumers and have a strong negotiation position because this low gas price. Additionally, greenhouse owners sometimes have own assets through which they can produce heat and/or electricity. This prosumer role also strengthens their negotiation position.

5.4.2 SENSITIVITY ANALYSIS COST-MODEL

To develop an understanding of the effects of uncertain developments in the district heating system on the total investment costs and the investment costs per MW system capacity, we have performed a sensitivity analysis. The sensitivity analysis of the cost-model was performed on one of the scenarios for district heating described in chapter 3, described as "Unforeseen". We have looked at the effect of changes in the development of demand, supply and infrastructure on the total investment costs and the relative investment costs (€/MW).

The sensitivity analysis shows that an increase or decrease of the investments in geothermal heat can result in 1% additional investment costs for the whole system. An increase or decrease of the capacity of residual heat sources per type of plant with 10% has less than 1% impact on the total investment costs. In comparison with geothermal heat sources, this effect is small. This can be explained by the fact that geothermal heat sources require initial investments that are up to 11 times higher than investing in residual heat sources, like waste-incinerators, or oil production plants, with the same capacity. This indicates that the uncertainty with regard to the development of geothermal heat poses a risk for the total investment costs of the system.

An increase of the demand density with 10% can result in 2% lower total investment costs, and a decrease in the demand density can result in 2% additional investment costs. Moreover, 10% additional length of the main transport infrastructure results in 2% additional investment costs and vice versa. Additional capacity of the primary heat transport network of 10% results in 1% additional investment costs and vice versa. Table 30 and 31 show the overview of the main results of the sensitivity analysis. The model has pointed out that the investment costs of district heating infrastructure in relation to the total system capacity are sensitive to the following factors: the density of the demand, the total heat demand, the detour factor, the length of the primary heat transport network, the capacity of the primary heat transport network and, the total capacity of geothermal heat sources.

These sensitivities pose a risk for the cost-effectiveness of district heating systems, especially given that the development of the heat demand, the related density of the demand and the necessary pipeline capacity and length are uncertain and depend on how the transition will proceed. Moreover, we see that the development of geothermal heat is very expensive in comparison to the development of residual heat sources. This is especially relevant for the approach of the PZH, which aims at high development of residual heat sources. Without specific policy that financially supports the development of geothermal heat sources, this may result in low development of residual heat.

Table 30 Main results sensitivity analysis cost model: effect on investment costs

	Effect on total investment costs (mln. €)			Effect on relative investment costs (mln. €/MW)		
	90%	100%	110%	90%	100%	110%
Density of the demand	€ 3.721	€ 3.906	€ 4.074	€ 2,3	€ 2,5	€ 2,6
Total demand	€ 3.626	€ 3.906	€ 4.195	€ 2,5	€ 2,5	€ 2,4
Detour factor	€ 3.745	€ 3.906	€ 4.068	€ 2,4	€ 2,5	€ 2,6
Length of the primary heat transport network	€ 3.838	€ 3.906	€ 3.975	€ 2,4	€ 2,5	€ 2,5
Capacity of the primary heat transport network	€ 3.873	€ 3.906	€ 3.938	€ 2,4	€ 2,5	€ 2,5
Total capacity of geothermal heat sources	€ 3.853	€ 3.906	€ 3.960	€ 2,4	€ 2,5	€ 2,5

Table 31 Main results sensitivity analysis cost model: effect on investment costs

	Effect on total investment costs (% change)			Effect on relative investment costs (€/MW) (% change)		
	90%	90%	90%	90%	100%	110%
Density of the demand	-4,7%	-4,7%	-4,7%	-8,0%	0,0%	4,0%
Total demand	-7,2%	-7,2%	-7,2%	0,0%	0,0%	-4,0%
Detour factor	-4,1%	-4,1%	-4,1%	-4,0%	0,0%	4,0%
Length of the primary heat transport network	-1,7%	-1,7%	-1,7%	-4,0%	0,0%	0,0%
Capacity of the primary heat transport network	-0,8%	-0,8%	-0,8%	-4,0%	0,0%	0,0%
Total capacity of geothermal heat sources	-1,4%	-1,4%	-1,4%	-4,0%	0,0%	0,0%
SUM	-20,0%	0,0%	19,8%	-24,0%	0,0%	4,0%

5.5 DISCUSSION AND CONCLUSION

In this chapter, we have adapted a model that can estimate the investment costs for district heating infrastructure to fit with the available information we have on the expectations of the PBL and the PZH about the development of district heating infrastructure in South Holland. We have simplified the existing model of the PBL and CE Delft regarding the spatial distribution of the demand and the spatial network design for different types of heat consumers. Additionally, we have transformed the formulas that describe the minimum and maximum cost-estimations for district heating infrastructure into a cost formula that calculates the average costs. We have added a formula to calculate the investment costs for heat storage. Moreover, we have added a formula that calculates the returns from the heat sales.

The model validation has pointed out that the investment costs are slightly higher than HVC would typically calculate. However, this can be explained by the scope of the cost-calculation. Moreover, the investment costs for gas-based plants seem high and the investment costs in geothermal heat are highly dependent on the actual production capacity of the well and the temperature regime of the network. Moreover, the returns from large-scale heat consumers, such as greenhouses can be expected to be lower than the highest marginal costs of heat production. This indicates large-scale heat consumers only purchase heat from a district heating network under certain favourable conditions.

The model has pointed out that the investment costs of district heating infrastructure in relation to the total system capacity are sensitive to the following factors: the density of the demand, the total heat demand, the detour factor, the length of the primary heat transport network, the capacity of the primary heat transport network and, the total capacity of geothermal heat sources. These factors are uncertain and as such, are an investment risk for the development of district heating infrastructure.

Important limitations of the model are:

- the simplifications with regard to the spatial outline of the network for different consumer groups,
- the limited validity of the formula for the investment costs in main heat transport pipelines that exceed 125MW,
- the limited insights in the potential ranges of the investment costs for different costs components and the effect on the margins for the total expected investment costs and,
- the necessity of a feasibility check on the energy balance within each cluster.

Moreover, in this planned development of infrastructure, initial investments in the primary heat infrastructure that facilitate network growth precede demand, and financial constructions are necessary that can support the initial over dimensioning of the heat infrastructure and mitigate investment risks. The timing of investments and returns is not included in the model. The model provides valuable insights in the effects of uncertainties about the development of infrastructure on the total and relative investment costs. However, the model can be further improved by solving the model limitations.

6.

MODEL RESULTS: COST EFFECTIVE CO_2 ABATEMENT THROUGH DISTRICT HEATING

What are the differences between the system designs for district heating infrastructure in South Holland with regard to CO_2 emissions, overall investment costs and costs of CO_2 abatement?

In chapter 3, four scenarios for the development of district heating networks are described. These scenarios represent possible system designs for the two transition pathways for district heating in South Holland. In chapter 4 and 5, we have developed, adapted and analysed two models that combined can calculate the marginal costs, investment costs and fixed costs related to district heating network operation. Moreover, we have seen that the uncertainties related to the scenarios in chapter 3, pose risks for the cost-effective development of district heating infrastructure and potentially affect the CO_2 abatement that can be achieved through transitioning to district heating. In this chapter, we will apply these two models on the four scenarios we have developed in chapter 3 to gain insights in the relative investment costs, operational costs and CO_2 abatement, and to develop an understanding of the effects of the uncertainties of the approaches on the expectations with regard to the optimality of the transition outcome. Firstly, we will discuss the model results per scenario. (6.1). Then the model results are compared in terms of the total heat production and CO_2 emissions (6.2), the investment costs (6.3) and the fixed costs (6.4). Finally, we will discuss the differences between the scenarios with regard to CO_2 emissions, overall investment costs and costs of CO_2 abatement (6.5). Detailed model results, including the use of the heat storage and load-duration curves can be found in appendix 6.

6.1 MODEL RESULTS PER SCENARIO

In this section, the model results of the economic dispatch model are discussed for each scenario individually. Firstly for the system as a whole and secondly for each cluster separately. This section provides insights in the system efficiency, the overall CO_2 emissions, the investment costs and the annual returns. Besides this, the overview shows the differences in heat production and consumption per region. It shows which heat sources are the most favourable and most accessible, based on the marginal costs of heat production, the CO_2 emissions and the constraints on production, consumption and transport. Moreover, the overview provides insights in which heat-sources are used for their full capacity and which heat sources have a remaining over-capacity and could thus supply more heat.

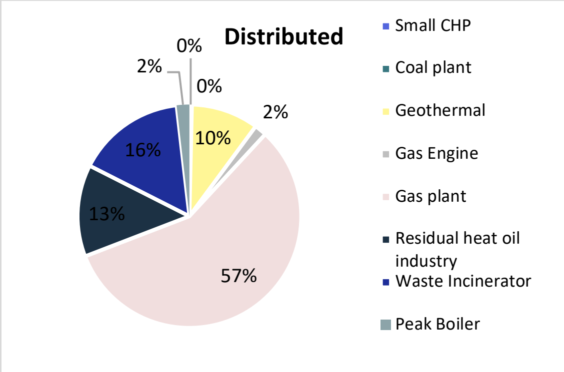
6.1.1 MODEL RESULTS SCENARIO: DISTRIBUTED

The distributed scenario is a potential transition outcome following the approach of the PBL. The distributed scenario consists of two clusters with isolated district heating networks; Leiden, and Dordrecht, and two district heating networks that connect multiple clusters: 1) the network connecting Lansingerland and Rotterdam North, and 2) the network connecting The Hague, Botlek and Rotterdam South. The model results show that the total heat production in this scenario is 4145 GWh, while the total demand is only 3463 GWh. The overall system efficiency is 85%; this corresponds with the heat losses in the distribution network, which are approximately 15% and a 1% heat loss in the transport network.

GENERAL MODEL RESULTS

Figure 32 shows that in the distributed scenario, 56% of the heat in South Holland is supplied though a gas fired electricity plant. Other important heat sources are the waste incinerators (16%), residual heat from the oil industry (13%) and the geothermal plants (10%). Peak boilers supply approximately 2% of the heat. However, this varies per cluster (figure 33).

Production



	Available capacity (MWh)	Average production (MWh)	% use
Small CHP	0	63	
Coal plant	0	0	
Geothermal	306	83	27%
Gas Engine	144	13	9%
Gas plant	140	27	20%
Residual heat oil industry	427	4	1%
Waste Incinerator	376	211	56%
Peak Boiler	374	71	19%

Storage

	# annual hours in-use	Average fill (MWh)	Max. cap. (MWh)
The Hague	5586	37	78
Dordrecht	0	0	11
Leiden	0	0	24
Lansingerland	3378	87	161
Rotterdam North	1566	15	16
Rotterdam South	5666	51	108

Transport

	Flow direction	Average use (MWh)	Max. cap. (MWh)
Europort	Out		
Botlek	In		
	Out	-63	-70
The Hague	In	7	9
Rotterdam North	In		
	Out		
Rotterdam South	In	56	61
	Out		
Lansingerland	In	193	347
	Out		
Dordrecht	In		
Leiden	In		

Figure 32 Overview heat production, storage and transport South Holland Distributed scenario

The total annual emissions in this scenario are approximately 171 kton CO_2. This means that for each MWh of supplied heat, 41 kg CO_2 is emitted. This is approximately a quarter the CO_2 that is emitted when the same amount of heat is supplied through individual boilers, which is approximately 192,6 kg/MWh. Compared to a heating system based on household size condensing boilers, this distributed district heating system achieves 74% CO_2 emission reduction. However, the impact on the total emissions from heating in South Holland remains low. Because only 14% of the heat demand is connected to one of the district heating networks, the annually achieved emission reduction in South Holland is only 10%.

MODEL RESULTS PER CLUSTER

Figure 33 shows the average production per cluster. The average hourly production is slightly higher than the average hourly demand, due to the modelled heat losses in the distribution and transport network. The distribution losses per cluster in this scenario range between 16% and 18% of the initial demand. Figure 33 also indicates the share of heat production per plant. Especially in Leiden and Rotterdam North the gas-fired electricity plant is a frequently used heat source. In Dordrecht and Rotterdam South, the main heat sources are the local waste incinerators. Lansingerland heavily depends on the heat import from the gas fired electricity plant in Rotterdam North. This is the main cause of the high CO_2 emissions in this scenario. On average, the hourly import of heat in Lansingerland is 193 MW and the pipeline is used constantly throughout the year. On average, 56% of the capacity of the pipeline between Rotterdam North and Lansingerland is utilized.

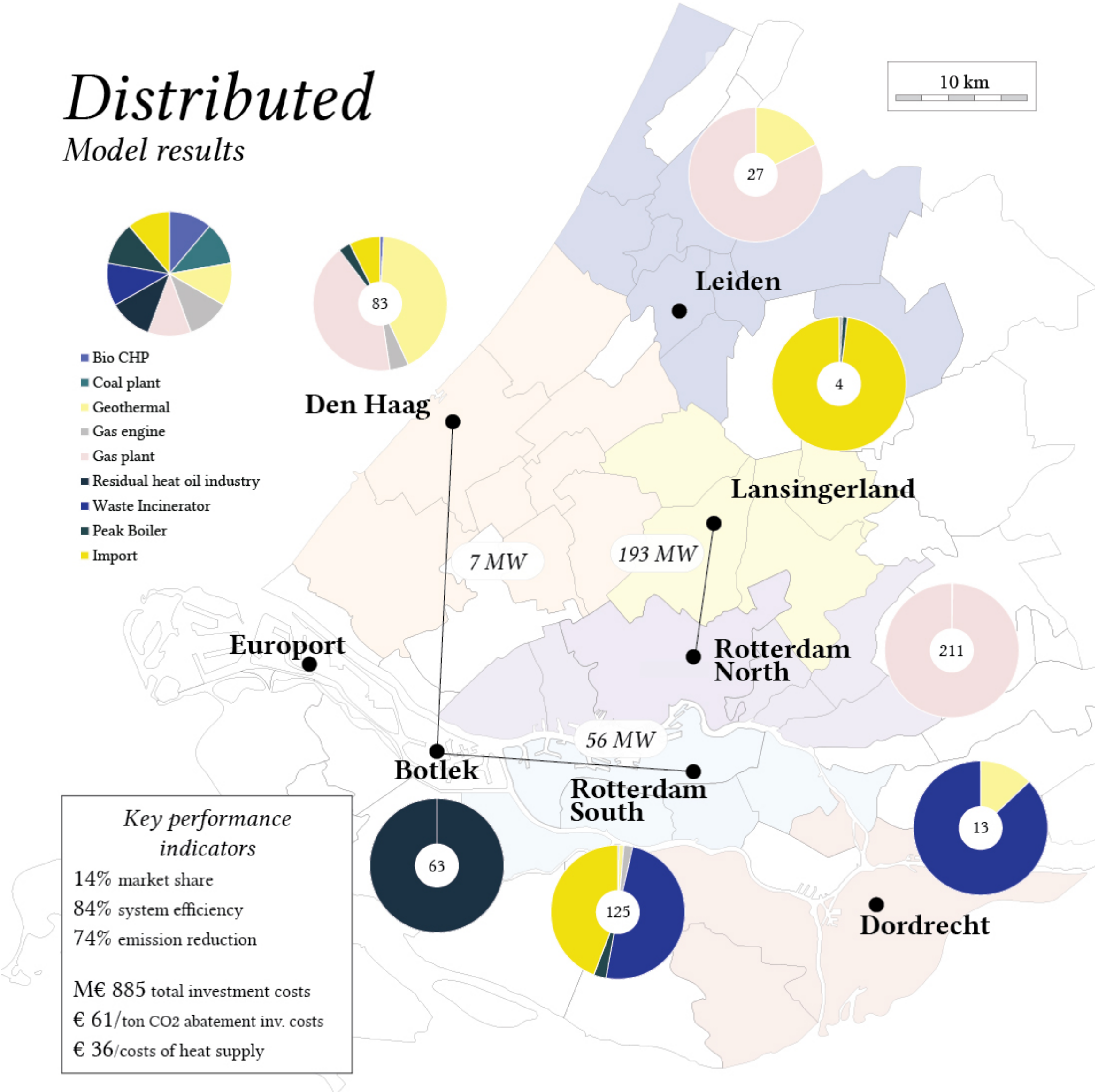


Figure 33 Overview outcome distributed scenario

The total estimated costs of investing in this infrastructure are approximately 885 million euro. Over an estimated lifetime of the infrastructure of 30 years, for each ton of avoided CO_2 emissions, this is an investment of 61€/ton. The total costs of heat supply, including marginal costs of heat production, costs of CO_2 emissions , the estimated maintenance costs and the depreciation of the network investment, are approximately 36€/MWh.

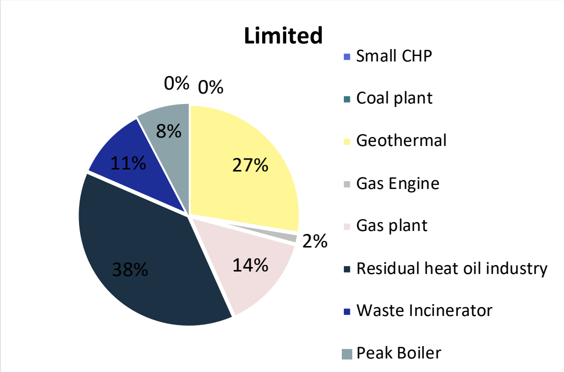
6.1.2 MODEL RESULTS SCENARIO: LIMITED

The Limited scenario is a potential transition outcome following the approach of the PZH. The model results show that the total heat production in the Limited scenario is 8400 GWh. This is approximately 21% higher than the heat demand in this scenario. The total emissions are approximately 269 kton CO_2. The distribution losses per cluster in this scenario range between 10% and 20%. On average, the heat losses in the distribution network are 17%. The total losses are 4% higher than the pre-determined heat losses in the distribution network. This indicates that approximately 4% of the total heat production is lost in heat transport.

GENERAL MODEL RESULTS

Compared to a heating system based on household size condensing boilers, this distributed district heating system achieves 79.9% CO_2 emission reduction. However, the impact on the total emissions from heating in South Holland is much smaller, as only 25% of the heat demand is connected to one of the district heating networks. For the heating system in South Holland as a whole, this means a reduction of 20% of the total emissions from low-temperature heating in households, greenhouses and utility buildings.

Production



	Available capacity (MWh)	Average production (MWh)	% use
Small CHP			
Coal plant	1178	0	0%
Geothermal	287,5	265	92%
Gas Engine	35	15	44%
Gas plant	1435	135	9%
Residual heat oil industry	625	366	59%
Waste Incinerator	626	104	17%
Peak Boiler	1734	73	4%

Storage

	# annual hours in-use	Average fill (MWh)	Max. cap. (MWh)
The Hague	5586	37	433
Dordrecht	0	0	52
Leiden	0	0	107
Lansingerland	3378	87	135
Rotterdam North	1566	15	46
Rotterdam South	5666	51	175

Transport

	Flow	Average (MWh)	Max. cap. (MWh)
Europort	Out	-3	-200
Botlek	In	3	200
	Out	-366	-505
The Hague	In	219	334
Rotterdam North	In	75	95
	Out	-77	-40
Rotterdam South	In	71	76
	Out	-3	-40
Lansingerland	In	77	166
	Out	-16	-126
Dordrecht	In	5	40
Leiden	In	16	126

Figure 34 Overview heat production, storage and transport South Holland Limited scenario

Figure 34 shows that in the Limited scenario. 27% of the heat in South Holland is supplied though geothermal plants. As such, geothermal plants are the most important heat source in this scenario. The geothermal heat sources supply 92% of their installed capacity. Peak boilers supply approximately 8% of the heat. However, this strongly varies per cluster (figure 35). Other important heat sources are residual heat from the oil industry (38%) waste incinerators (11%), and gas fired electricity plants (14%). There are no small CHPs in this scenario and the residual heat from the coal fired electricity plant located in the Europort cluster is only used for 2% of its available capacity.

The relative CO_2 emissions per supplied MWh of heat are lower in this scenario than in the Distributed scenario. This has two main reasons. Firstly, there is a much larger capacity of geothermal heat, almost six times the capacity in the Distributed scenario, while the demand is only 10% points higher. Besides this, the oil industry in the Botlek is a zero-emission heat source. The main transport infrastructure makes this residual heat source in the Rotterdam Harbour available in all clusters, where in the Distributed scenario this heat is only available in The Hague and Rotterdam South.

MODEL RESULTS PER CLUSTER

Figure 39 shows the average production per cluster, the share of heat production per plant and the average utilization rate of the heat infrastructure.

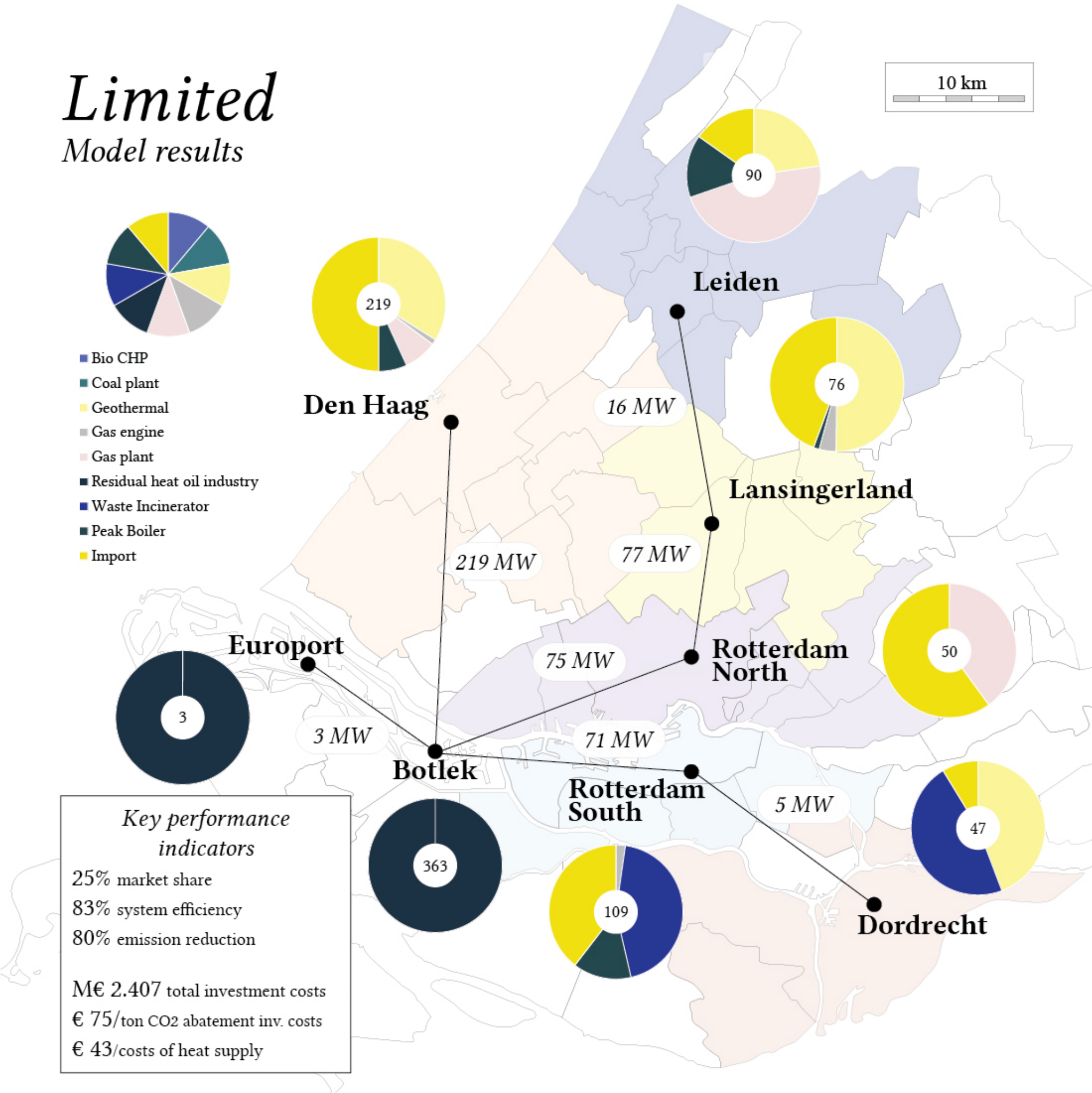


Figure 35 Output Limited scenario

The total estimated costs of investing in this infrastructure are approximately 2407 million euro. Over an estimated lifetime of the infrastructure of 30 years, for each ton of avoided CO_2 emissions, this is an investment of 75€/ton. The total costs of heat supply, including marginal costs of heat production, costs of CO_2 emissions , the estimated maintenance costs and the depreciation of the network investment, are approximately 43€/MWh.

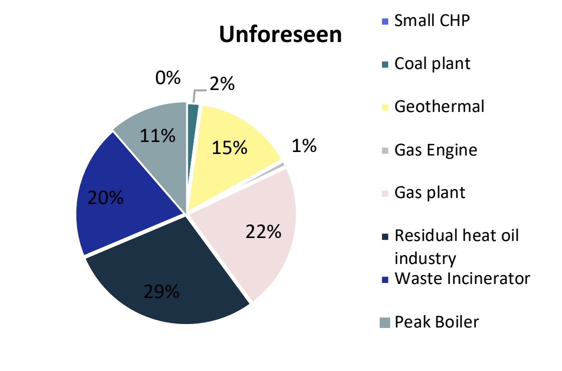
6.1.3 MODEL RESULTS SCENARIO: UNFORESEEN

The total heat production in the Unforeseen scenario is 16965 GWh. This is approximately 21% higher than the modelled heat demand. The percentage heat losses in the transport network in this scenario is similar to the percentage heat loses in the Limited scenario. Compared to a heating system based on household size condensing boilers, this district heating system achieves 69,6% CO_2 emission reduction. However, the impact on the total emissions from heating in South Holland is smaller, as only 50% of the heat demand is connected to one of the district heating networks. For the heating system as a whole, this means a reduction of 34,8% of the total emissions.

GENERAL MODEL RESULTS

Figure 36 shows that in the Unforeseen scenario, 29% of the heat is supplied residual heat in the oil industry. The high supply of residual heat from the Botlek area is possible due to relatively large pipeline capacities from the Botlek to the connecting clusters. The capacity of the residual heat of the oil industry in the Botlek is used for 89%. The second largest heat source are the gas plants (22%). The geothermal heat sources only supply 15% of the heat. This is mostly because of the relatively low installed capacity of geothermal heat sources. The overview shows that the capacity of the geothermal heat sources is used for 99% throughout the year.

Production



	Available capacity (MWh)	Average production (MWh)	% use
Small CHP			
Coal plant	1178	41	
Geothermal	287,5	286	99%
Gas Engine	35	20	56%
Gas plant	1435	423	29%
Residual heat oil industry	625	554	89%
Waste Incinerator	626	386	62%
Peak Boiler	3469	219	6%

Storage

	# hours annually in-use	Average fill (MWh)	Max. cap. (MWh)
The Hague	6592	546	865
Dordrecht	3636	29	104
Leiden	3718	114	213
Lansingerland	1961	99	269
Rotterdam North	2777	56	92
Rotterdam South	3616	165	349

Transport

	Flow	Average (MWh)	Max. cap. (MWh)
Europort	Out	-138	-200
Botlek	In	138	200
	Out	-926	-1205
The Hague	In	619	817
Rotterdam North	In	91	95
	Out	-212	-304
Rotterdam South	In	216	293
	Out	-8	-40
Lansingerland	In	213	304
	Out	-41	-73
Dordrecht	In	8	40
Leiden	In	41	73

Figure 36 Heat production South Holland Unforeseen scenario

The demand in this scenario pushes the heat production from zero-emission heat sources to the limit. Only the residual heat from the oil industry in the Europort area has substantial capacity left (approximately 75 MW on average). The expectation is that when the demand increases, while the production capacity stays the same, the CO_2 intensity of heat supply will increase.

MODEL RESULTS PER CLUSTER

Figure 37 shows the average production per cluster, the share of heat production per plant and the average utilization rate of the heat infrastructure.

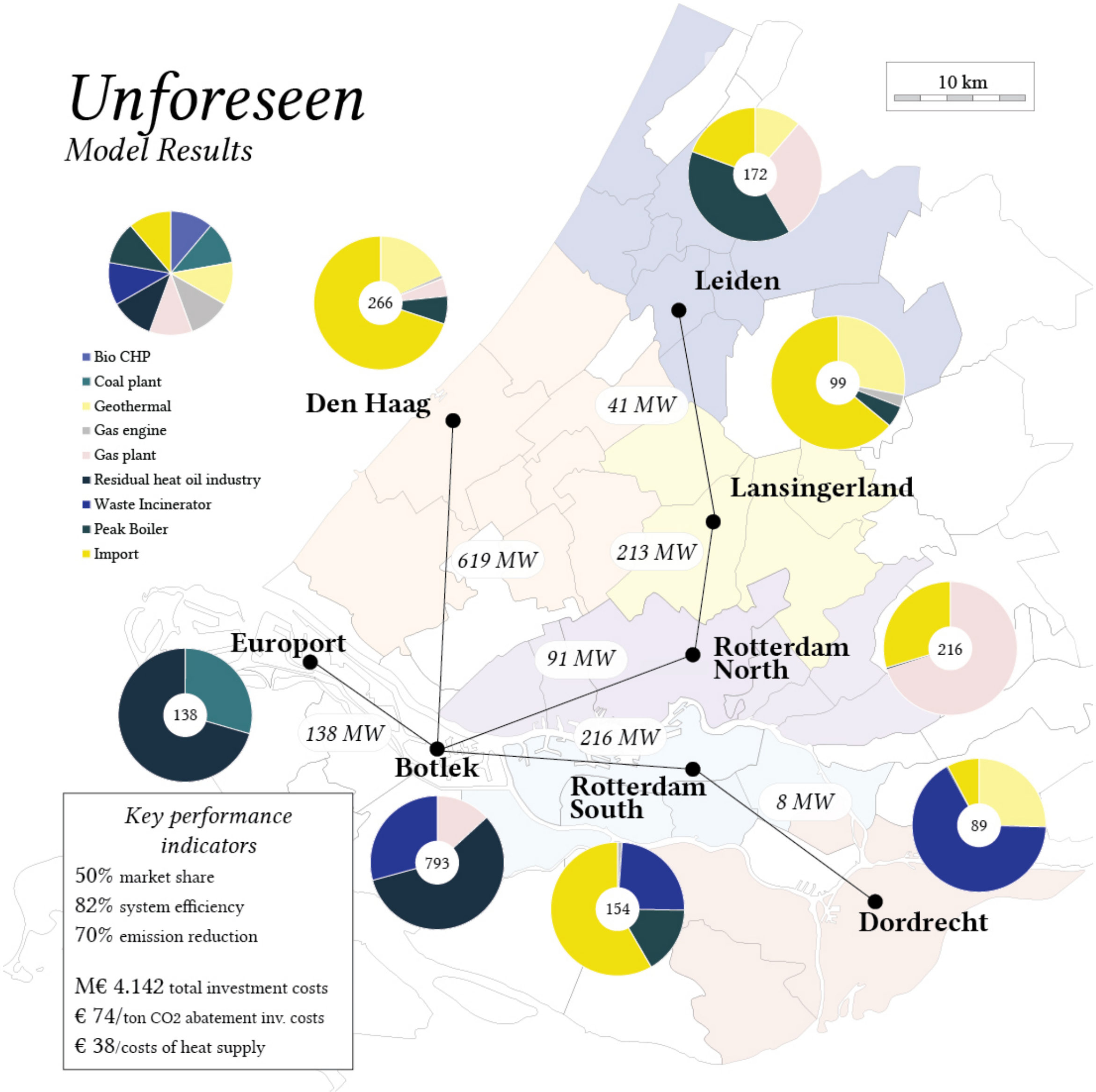


Figure 37 Output Unforeseen scenario

The total estimated costs of investing in this infrastructure are approximately 4142 million euro. Over an estimated lifetime of the infrastructure of 30 years, for each ton of avoided CO_2 emissions, this is an investment of 74€/ton. The total costs of heat supply, including marginal costs of heat production, costs of CO_2 emissions , the estimated maintenance costs and the depreciation of the network investment, are approximately 38€/MWh.

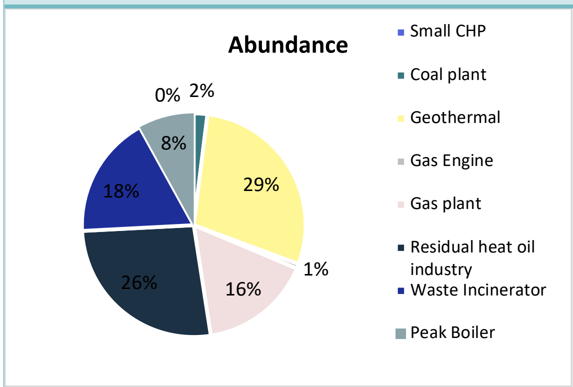
6.1.4 MODEL RESULTS SCENARIO: ABUNDANCE

The total heat production in the Abundance scenario is 16451GWh. This is approximately 21% higher than the heat demand. The heat losses in the transport network are therefore approximately the same as in the Limited and Unforeseen scenario. Compared to a heating system based on household size condensing boilers, this district heating system achieves 82,2% CO_2 emission reduction. This is more than the CO_2 abatement achieved in the Limited scenario and the Unforeseen scenario.

GENERAL MODEL RESULTS

Only 50% of the heat demand is connected to one of the district heating networks (figure 38). For the heating system as a whole, this means a reduction of 41,1% of the total emissions. This is six percentage points more than the Unforeseen scenario. The largest heat source are the geothermal wells (29%) and the second largest heat source is the residual heat from the oil industry (26%).

Production



	Available capacity (MWh)	Average production (MWh)	% use
Small CHP			
Coal plant	1178	38	
Geothermal	600	553	92%
Gas Engine	35	13	38%
Gas plant	1435	312	22%
Residual heat oil industry	625	513	82%
Waste Incinerator	626	343	55%
Peak Boiler	3469	154	4%

Storage

	# hours annually in-use	Average fill (MWh)	Max. cap. (MWh)
The Hague	6297	528	865
Dordrecht	1739	48	104
Leiden	3304	89	213
Lansingerland	4758	142	269
Rotterdam North	2234	30	92
Rotterdam South	3495	161	349

Transport

	Flow	Average (MWh)	Max. cap. (MWh)
Europort	Out	-127	200
Botlek	In	127	200
	Out	-810	1321
The Hague	In	518	933
Rotterdam North	In	75	95
	Out	-159	460
Rotterdam South	In	218	293
	Out	0	40
Lansingerland	In	159	460
	Out	-26	151
Dordrecht	In	0	40
Leiden	In	26	151

Figure 38 Heat production abundance scenario

MODEL RESULTS PER CLUSTER

Figure 39 shows the average production per cluster, the share of heat production per plant and the average utilization rate of the heat infrastructure.

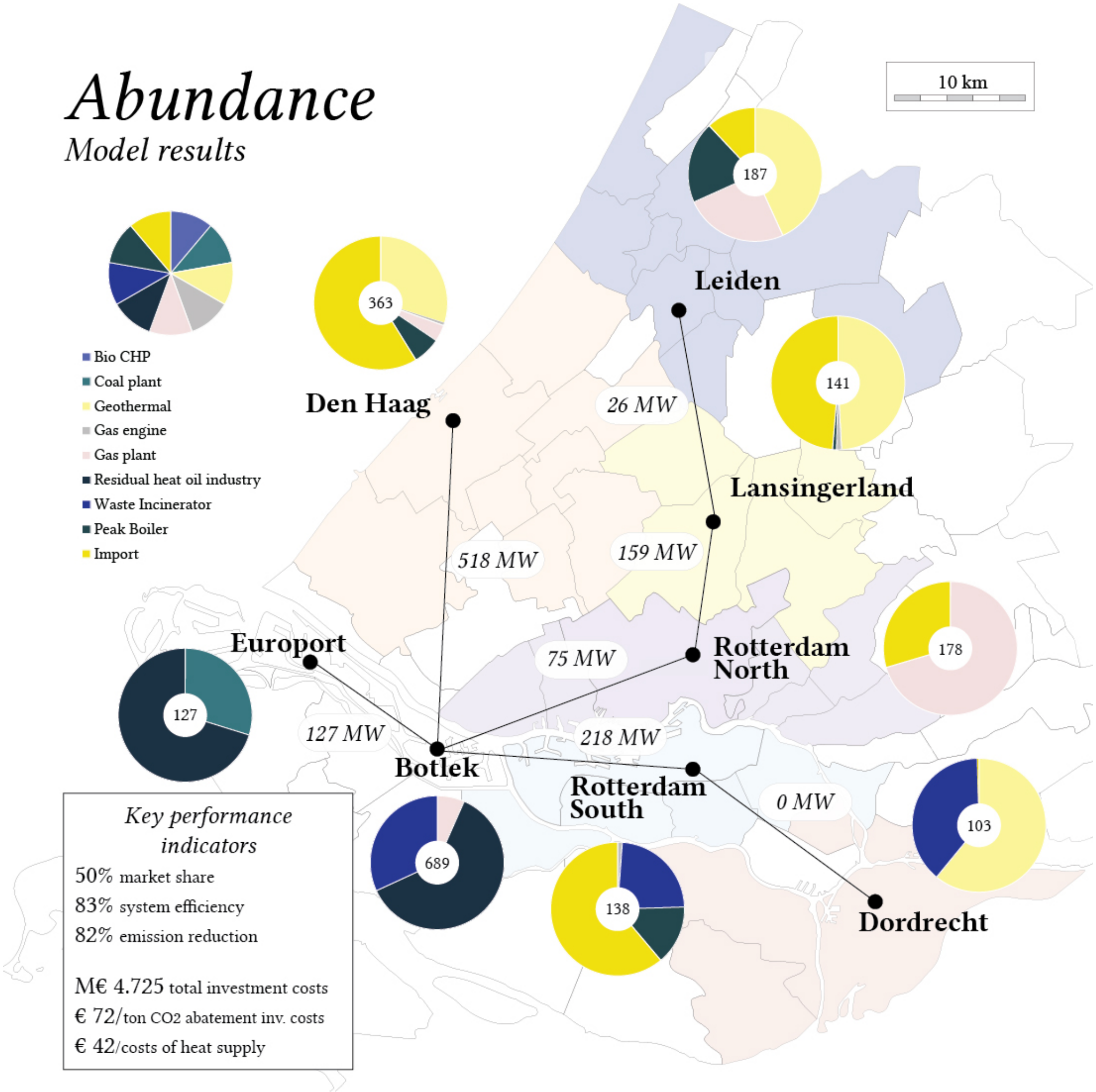


Figure 39 Output Abundance scenario in MW

The total estimated costs of investing in this infrastructure are approximately 4725 million euro. Over an estimated lifetime of the infrastructure of 30 years, for each ton of avoided CO_2 emissions, this is an investment of 72€/ton. The total costs of heat supply, including marginal costs of heat production, costs of CO_2 emissions , the estimated maintenance costs and the depreciation of the network investment, are approximately 42€/MWh.

6.2 CO_2 EMISSIONS AND MARGINAL COSTS OF HEAT PRODUCTION

In section 6.1.1-6.1.4 the model results are discussed for each scenario separately. In section 6.2-6.6, the heat production and resulting CO_2 emissions, the investment costs, the fixed costs and the maintenance costs and the resulting total costs of heat production of the four scenarios are compared.

6.2.1 COMPARISON OF CO_2 EMISSIONS

Figure 40 shows the average CO_2 emissions from district heating in each of the scenarios, and the average CO_2 emissions from heating with a condensing boiler, which is currently the most common heating method. In each of the scenarios for district heating, the CO_2 average emissions are much lower than the emissions from individual boilers. This confirms that a district heating network is a much cleaner alternative for low-temperature heating than an individual boiler. The results also show that there is a large difference between the average CO_2 emissions in the scenarios of the PZH and the scenario of the PBL. The scenarios of the PZH result in approximately half the average CO_2 emissions of the average CO_2 emissions of the scenario of the PBL. The differences between the CO_2 emissions from district heating in the scenarios of the PZH are limited to a few percentage points.

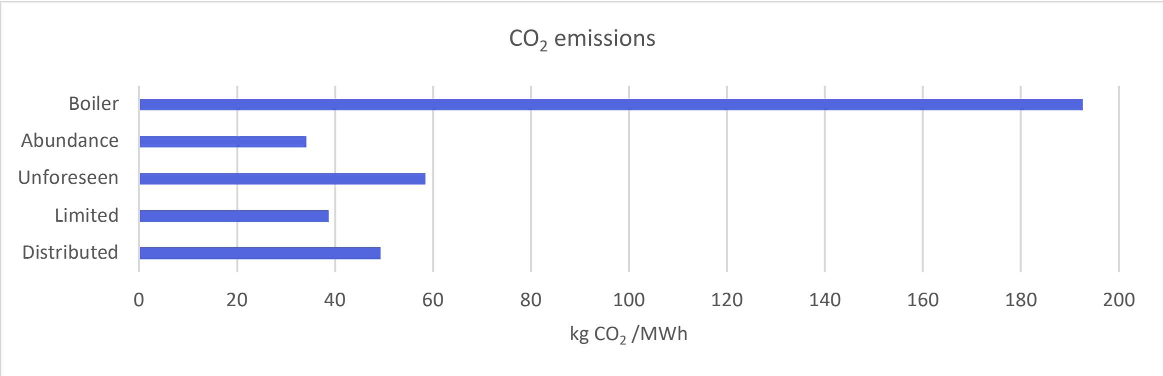


Figure 40 CO_2 emissions per MWh supplied heat for each scenario

Figure 41 shows the average CO_2 emissions per MWh produced heat in each of the scenarios. Except from the cluster of Rotterdam North, the average CO_2 emissions per cluster vary strongly between the scenarios. Especially in Lansingerland, the difference is large. This however, says nothing about the CO_2 density of the consumed heat, as this depends on the CO_2 emissions associated with the heat in the infrastructure.

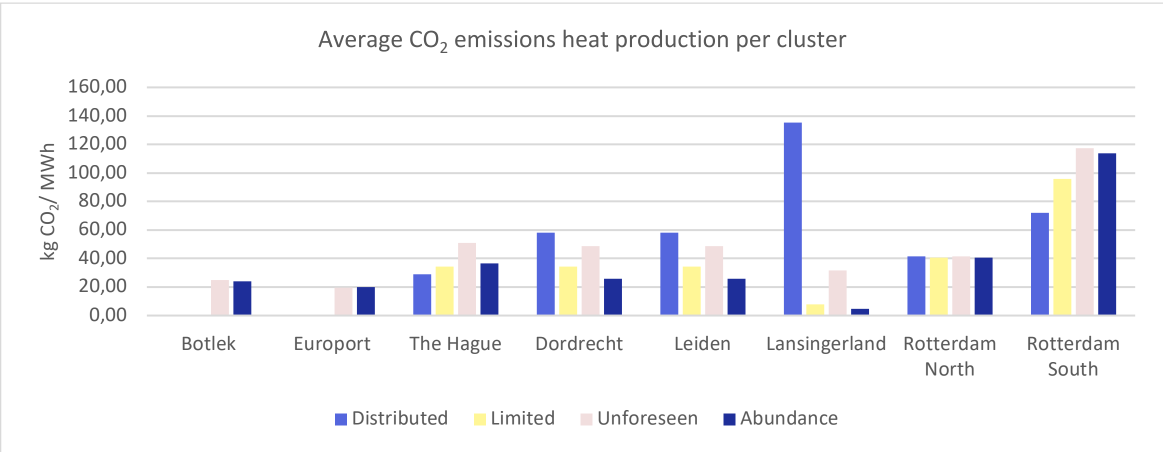


Figure 41 Average CO_2 emissions per cluster in ton CO_2/MWh

Table 32 shows home these levels of CO_2 abatement relate to the national Dutch annual CO_2 emissions.

Table 32 Overview total CO_2 emissions per scenario

	Distributed	Limited	Unforeseen	Abundance	
Absolute CO_2 abatement	0,20	0,40	0,53	0,86	Mton
National CO_2 emissions	187	187	187	187	Mton
% of national CO_2 emissions	0,1%	0,2%	0,3%	0,5%	%

6.2.2 COMPARISON OF OPTIMAL ANNUAL DISPATCH SCHEDULE

The differences in CO_2 emissions per scenario can be explained by the origin of the heat and the heat losses throughout the system. Figure 42 shows the origin of heat per scenario for all four scenarios.

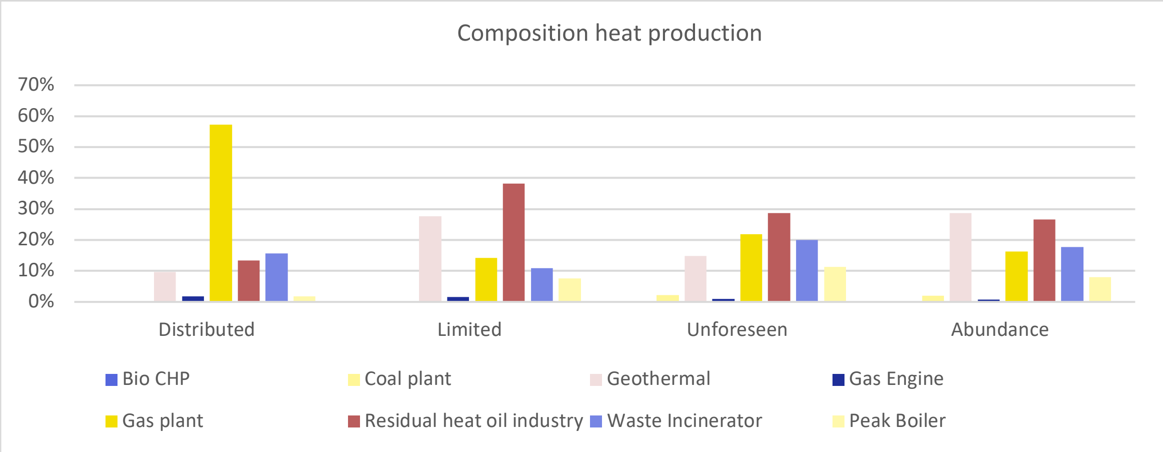


Figure 42 Origin of heat per scenario – type of plant

Figure 42 shows the Distributed scenario of the PBL is very dependent on the available gas fired plants, which have relatively high CO_2 emissions (0,0408 ton CO_2/MWh). 59% of the heat in this scenario comes from gas fired electricity plants. Figure 42 also shows that in the scenarios of the PZH, local sources of geothermal heat and the residual heat from the oil industry in the Botlek represent the two most important heat sources in the base-load. These are both low-emission heat sources (0 ton CO_2/MWh). Appendix 6 provide more detailed data on the energy flows through the district heating networks and the origin of the heat consumed per cluster.

6.3 INVESTMENT COSTS

The investment costs are calculated using the model described in chapter 4. In 6.3.1 the total investment costs are discussed and in 6.3.2 the annual depreciation costs of the investments are disused.

6.3.1 TOTAL INVESTMENT COSTS

The investment costs consist of the connection costs of base-load plants, the investment costs in the heat transport network, the heat transfer stations, the secondary network, the subs-stations, the distribution network and the heat storage. The total investment costs are the highest for the Abundance scenario and the lowest for the Distributed scenario. Table 33 shows the investment costs in the district heating network per scenario. The Distributed scenario costs 885 million euro, the Limited scenario costs 2407 million euro, the Unforeseen scenario costs 4142 million euro and the Abundance scenario costs 4725 million euro to realize. The largest two cost-components are connection of base-load plants followed by the secondary heat network. The third largest cost component is the main heat transport infrastructure.

Table 33 Total investment costs per scenario

	Distributed	Limited	Unforeseen	Abundance	
Connection costs base load plants	€ 231	€ 717	€ 851	€ 1.357	Mln. €
Heat transport network	€ 174	€ 673	€ 919	€ 995	Mln. €
Heat transfer stations	€ 42	€ 84	€ 169	€ 169	Mln. €
Secondary network	€ 330	€ 704	€ 1.759	€ 1.759	Mln. €
Substation	€ 30	€ 59	€ 117	€ 117	Mln. €
Distribution network	€ 50	€ 99	€ 198	€ 198	Mln. €
Heat storage	€ 30	€ 71	€ 128	€ 128	Mln. €
Total	**€ 885**	**€ 2.407**	**€ 4.142**	**€ 4.725**	**Mln. €**

However, the market share for district heating strongly varies per scenario. Figure 43 shows the total investment costs scaled to the market share, for each of the scenarios.

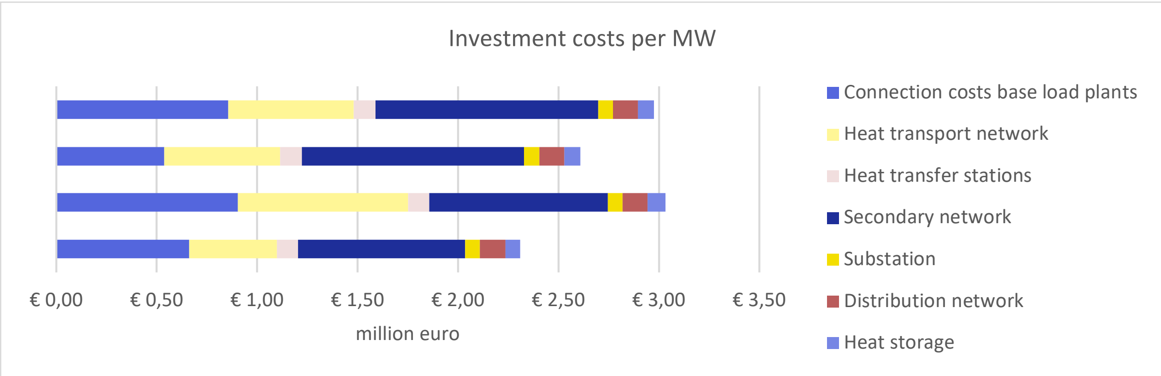


Figure 43 Investment costs per MW

The three scenarios following the approach of the Province of South Holland lead to the highest investment costs, both in absolute and in relative terms. The scenario following the approach of the PBL towards developing district-heating results in the lowest investment costs. This is also true when the investment costs are scaled to the system capacity. The investment costs in the Distributed scenario are between 14% and 26% lower than in the scenarios following the approach of the Province of South Holland for the development of district heating. The high investment costs in the approach of the PZH result from the large installed capacity for geothermal heat and the additional investments for the main transport infrastructure and secondary heat infrastructure.

6.3.2 ANNUAL DEPRECIATION INVESTMENT COSTS

To calculate the annual costs of heat supply the investment costs need to be depreciated over the technical lifetime of the infrastructure. The technical lifetime of a district heating transport- and distribution-network is on average 40 years (Connolly et al., 2014). The technical lifetime time of other infrastructural components is usually shorter, in the range of 20-30 years (table 34).

Table 34 Technical lifetime components district heating networks (Connolly et al., 2014)

Component	Technical lifetime (years)
Pipelines	40
Industrial surplus heat source	30
Geothermal heat source	25
Heat from waste incineration	20
Solar thermal heat source	20
Heat from boilers	20
Substation	20

Figure 44 shows the depreciation of investment costs per scenario in million euro per MWh.

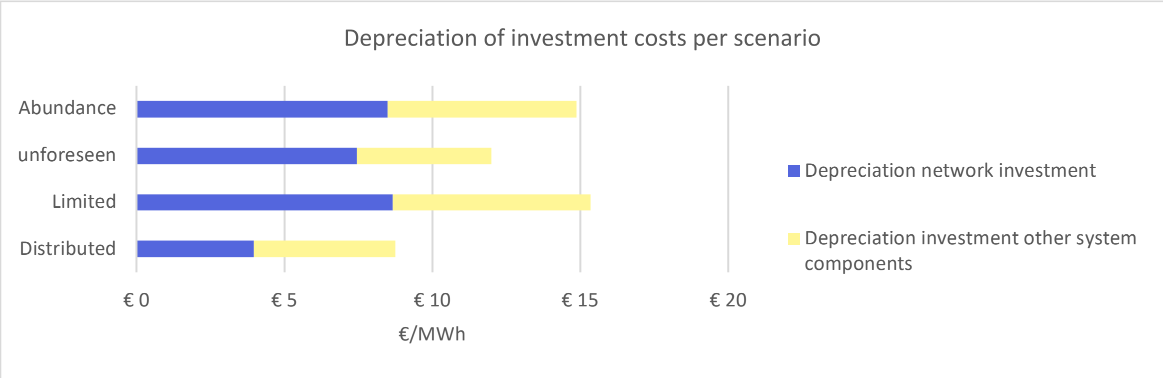


Figure 44 Annual costs per scenario in €/MWh

The depreciation of the investment costs per MWh supplied heat is the highest in the Limited scenario. In this scenario the investment costs are relatively the highest in comparison to the expected annual heat supply. As discussed in 6.3.1 this is caused by the relatively expensive main heat transport infrastructure and the relatively high investments in (expensive) geothermal heat sources.

6.4 FIXED COSTS

Table 35 shows the total annual fixed costs per scenario in million euro and the annual fixed costs per MW system capacity in million euro. The maintenance costs are the largest fixed-cost component. The relative fixed costs are the lowest in the Distributed scenario and the highest in the Limited scenario. However, the differences in fixed costs are small. The fixed costs consist of the maintenance costs and the precario tax.

Table 35 Annual fixed costs per scenario in million euro

	Distributed	Limited	Unforeseen	Abundance	
Maintenance costs	€ 11,1	€ 29,3	€ 48,6	€ 52,1	Mln. € /year
Precario tax	€ 5,6	€ 11,8	€ 27,6	€ 27,6	Mln. € /year
Total annual fixed costs	€ 16,6	€ 41,2	€ 76,2	€ 79,7	Mln. € /year
Fixed costs	€ 24,6	€ 12,9	€ 12,0	€ 12,5	€/MWh

6.4.1 COMPARISON OF MAINTENANCE COSTS

The maintenance costs are estimated as a percentage of the investment costs. Table 36 shows the annual maintenance costs per scenario. The annual maintenance costs are the lowest for the Distributed scenario and the highest for the Abundance scenario. The largest cost component for the maintenance costs, is the maintenance of the base-load plants. Table 36 shows the maintenance costs per MWh per scenario. The Distributed scenario is still the cheapest and the Limited scenario is the most expensive per MW. The maintenance costs are relatively high in the Limited scenario as a result of the relatively high investment costs in base-load plants and the heat transport network.

Table 36 Maintenance costs per scenario

	Distributed	Limited	Unforeseen	Abundance	
Base load plants	€ 3,5	€ 10,9	€ 16,4	€ 19,1	Mln. € /year
Heat transport network	€ 1,7	€ 6,7	€ 9,2	€ 10,0	Mln. € /year
Heat transfer stations	€ 1,3	€ 2,5	€ 5,1	€ 5,1	Mln. € /year
Secondary network	€ 1,9	€ 3,5	€ 6,9	€ 6,9	Mln. € /year
Substation	€ 0,9	€ 1,8	€ 3,5	€ 3,5	Mln. € /year
Distribution network	€ 1,2	€ 2,5	€ 5,0	€ 5,0	Mln. € /year
Heat storage	€ 0,6	€ 1,4	€ 2,6	€ 2,6	Mln. € /year
Annual maintenance costs	€ 10,3	€ 27,8	€ 46,2	€ 48,1	Mln. € /year
Maintenance costs per MWh	€ 3,19	€ 4,22	€ 3,50	€ 3,74	€/MWh

6.4.2 COMPARISON OF PRECARIO TAX

The precario-tax is the annual municipal tax on the use of public land and varies per municipality. The precario tax needs to be paid for the length of the transport and distribution network. Table 37 shows the network length per scenario. The total network length consists of the estimated length of the distribution network, the secondary transport network and the primary transport network. CE Delft estimated the average precario tax for district heating networks at 4.3 euro/meter (CE Delft, 2016).

Table 37 Estimated length network in KM and precario tax per scenario in million euro

	Distributed	Limited	Unforeseen	Abundance	
Total length network	1293	2754	6416	6416	km
Annual precario tax	€ 5,6	€ 11,8	€ 27,6	€ 27,6	Mln. € /year
Precario costs €/MWh	€ 1,6	€ 1,7	€ 2,0	€ 2,0	€/MWh

6.5 DISCUSSION AND CONCLUSION

We have started this chapter with the question: *What are the differences between the system designs for district heating infrastructure in South Holland with regard to CO_2 emissions, overall investment costs and costs of CO_2 abatement?.* To answer this question, we have applied the models we have developed in chapter four and five on the four scenarios we have developed in chapter three. We have gained insights in the total and relative investment costs, operational costs and CO_2 abatement (table 38). Based on these model results, we have identified a trade-off between the cost-effectiveness of the investment, and the achieved relative and total CO_2 abatement. We can clearly see that as the systems become relatively more expensive per MW system capacity, due to additional infrastructure and geothermal heat sources, the level of CO_2 abatement increases. Additionally, we can see that to achieve these high levels of relative cost abatement; we compromise on the effectiveness of the investment.

Table 38 Main model outcomes

	Distributed	Limited	Unforeseen	Abundance	
Investment costs	€ 885	€ 2.407	€ 4.142	€ 4.725	Mln. €
Relative investment costs	€ 2,3	€ 3,0	€ 2,6	€ 3,0	Mln. € /MW
Total annual CO_2 abatement	498	1070	1864	2203	Kton CO_2
Relative CO_2 abatement	74,4%	79,9%	69,6%	82,2%	% kg/per MWh supplied heat
Effectiveness of investment	16	13	14	14	Kg avoided CO_2/ €

Based on this comparison of the approaches, a trade-off appears between cost-effective CO_2 abatement, and maximizing the overall reduction of CO_2 emissions. In which the scenarios of the PZH in general result in higher levels of CO_2 abatement and the scenario of the PBL is more cost-effective. Additionally, in the light of the full phase-out of natural gas the approach of the PZH appears to provide better opportunities to realize large-scale district heating. The PZH expects that this is a cost-effective alternative for the current gas-based system. This is supported by the analysis, which shows heat supply costs of €36/ MWh in the scenario of the PBL and heat supply costs of €38-43/ MWh in the scenarios of the PZH. While the costs are higher, they do not nearly compare to the 2,25€/m^3 or 230 €/MWh the PBL expects necessary for a full phase-out of natural gas.

7.

UNCERTAINTIES AND RISKS FOR THE REGIONAL HEAT TRANSITION

In chapter three to six, we have answered the sub-questions 1.1-1.4. We have presented the research results, discussed them and we have drawn conclusions based on the results to answer the research questions. However, throughout the thesis, we have not yet answered the fifth sub-question: What are the main uncertainties and risks with regard to the two approaches for developing district heating, for the development of district heating at a municipal level?. To answer this sub-question, we will briefly recap the research results. Thereafter, we will discuss the identified differences between the approaches and we will describe the main uncertainties and risks of these approaches for municipal policy making in the heat transition. We start with the risks related to the transition process (7.1), followed by the risks associated with the forecasting methods (7.2), and the uncertainties regarding the forecasts (7.3). In 7.4, we evaluate the effect of identified data uncertainties on the policy target, and in 7.5, we propose risk mitigation measures. In 7.6, we draw a conclusion about the main uncertainties and risks in the heat transition we have identified in this thesis.

What are the main uncertainties and risks with regard to the two approaches for developing district heating, for the development of district heating at a municipal level?

7.1 RISKS RELATED TO THE TRANSITION PROCESS

In chapter 3, we have answered sub question 1.1 *hat are the main conceptual differences between the two approaches for the development of a province-wide district heating approach for South Holland?* To answer this question, we have performed a grey literature search and we have consulted the PBL and the PZH. This has led to insights in the differences between the approaches with regard to the transition process. In this section, we will discuss these differences and we will link the approaches to a theoretic frame on energy transition to gain additional insights in the risks associated with the approaches.

7.1.1 TRANSITION PROCESS

The approach of the PBL is local and market driven. This approach does not require commitments to district heating as the main alternatives for natural gas. In addition, while realizing public support remains important, it is not necessary to realize broad public support for a single technology. The downside of this free approach to transitioning is that there is not necessarily alignment between the different initiatives for phasing-out natural gas, which can lead to system inefficiencies. Moreover, the approach depends on the initiative of market parties and residents. The municipality therefore needs to reduce information barriers by evaluating local opportunities for the phase-out of natural gas, initiate local change based on these opportunities and align transition initiatives where possible. Moreover, the municipality has an important role in guiding and monitoring local technical and institutional decisions. However, the municipality has no legal options through which it can enforce the market uptake of the transition, or to apply minimum quality requirements on the transition outcome. Moreover, the municipality is not in the position to change the market conditions. The success of the transition depends on the extent to which the municipality is able to activate residents and (local) companies to take initiative in the transition. Additionally, the success depends on the extent to which the municipality is able to coordinate and align these initiatives.

The approach of the PZH is regional and plan driven. There is a strong actor coalition, which is willing and able to make investments in this central district heating infrastructure, when the demand is secured. Moreover, the large network is expected to benefit from an open market and a multitude of heat producers. The Heat Alliance, the actor coalition commit to realizing the infrastructure, unburdens municipalities when it comes to the economic, technical and institutional aspects of the implementation of large district heating infrastructure and aligning local transition plans into a regional strategy. With regard to the formulation of heat transition plans, municipalities will collaborate with the Province and adhere with the transition plans that are initiated at a provincial level. On the one hand the municipality needs to investigate in which districts is a feasible alternative for natural gas, financially, socially and technically. On the other hand, in many municipalities, the development of district heating networks will depend on the Heat Alliance for realizing the availability of district heat. In this planned development of infrastructure, initial investments in the primary heat infrastructure that facilitate network growth precede demand, and financial constructions are necessary that can support the initial over dimensioning of the heat infrastructure and mitigate investment risks.

Broad public support is a prerequisite for realizing this approach towards developing district heating. However, there is no legal framework in place to enforce the phase-out of natural gas (Planbureau voor de Leefomgeving, 2017a). The municipality finds itself in a position where upfront commitment towards district heating is a prerequisite for transitioning, however individual mandate of residents limits the actual commitments the municipality can make. The success of the transition depends on the extent to which municipalities are able to develop a local support base for the transition plans. This local support base does not end at the municipal boundaries. Due to the scale of the transition plans, interdependencies between municipalities will arise.

7.1.2 LINK TO THEORY

Cherp et al. (2018) have researched how existing scientific literature evaluate and aim to explain energy transitions. They have developed a framework in which they broadcast the top-level variables associated with the three perspectives on national energy transitions present in literature: techno-economic, political and socio-technical. These two approaches can be placed within this framework for analysing national energy transitions (figure 45).

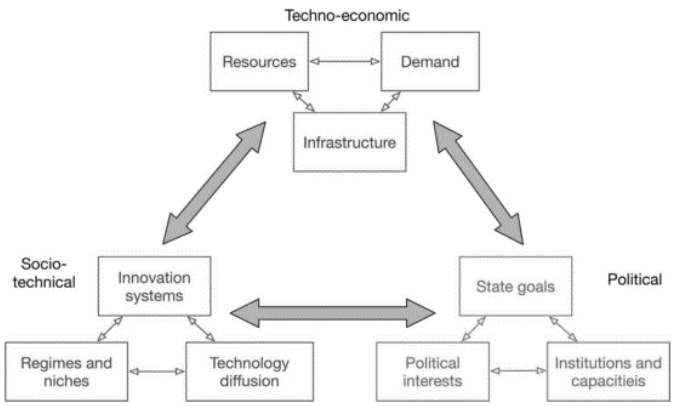


Figure 45 Framework of top-level variables associated with the three perspectives on national energy transitions (Cherp, Vinichenko, Jewell, Brutschin, & Sovacool, 2018)

The approach of the PBL fits with the techno-economic perspective on energy transitions. From a techno-economic perspective, energy systems, like the heating system in South Holland, are defined by flows (extraction and conversion) and processes (production and consumption), and may be coordinated through markets (Cherp et al., 2018). Central concepts in this perspective are: resources, services, demand, infrastructure and prices (Cherp et al., 2018). Energy systems can be represented in quantitative models as both physical and economical aspects of energy systems can be quantified. In this perspective on energy transitions, actors are usually assumed rational, utility optimizing entities and policies appear as external, exogenous assumptions or normative targets (Cherp et al., 2018). Moreover, from this perspective there is no evaluation to determine under what conditions policy-makers would adapt policies or pursue set goals (Cherp et al., 2018). The downsides of adopting a techno-economic perspective on energy transitions are (Cherp et al., 2018):

1) Policies can become exogenous assumptions or normative targets, rather than objects for analysis, understanding and explanation.
2) Radical technological innovations can often not be predicted by techno-economic models.
3) The social reality of the transition is not necessarily part of the analysis; the conditions under which actors are actually willing to adopt policies or able and willing to demonstrate certain behaviour.

The approach of the PZH for evaluating the potential for district heating in the heat transition fits better with the political perspective on energy transitions. The PZH pursues national and international interests with regard to cost-effective CO_2 abatement, local industrial interests with regard to efficient use of existing streams of waste-heat and local residents' interests with regard to wide-availability of district heating infrastructure and the potential to realize an affordable, low emissions heating system for all residents. In this process, the PZH collaborates with the parties in the Heat Alliance. Moreover, the PZH is a member of several administrative consultations in which companies and governmental organizations develop knowledge on the conditions under which the transition can be accelerated. The main downsides of adopting a political perspective on energy transitions are (Cherp et al., 2018):

1) Safeguarding the balanced representation of interests in the transition process is difficult.
2) There is usually a poor representation of material factors.

7.2 RISKS RELATED TO THE FORECASTING METHODS

RQ 1.2: What are the main differences between the methods the PBL and the PZH deploy to develop scenarios about the development of district heating systems in South Holland?

In this section, we will discuss the risks that are related to the forecasting methods the PBL and the PZH deploy. The link to the theory on energy transitions, as described in 7.1.1 is also clearly visible in the difference between the forecasting approaches the two institutes deploy.

7.2.1 VESTA/MAIS MODEL

In the approach of the PBL, the development of district heating is simulated in the Vesta/MAIS model. This is a techno-economic model where the development of district heating is forecasted through local cost-minimizing decisions. The model allows for testing the effects of policy that either enforces or provides financial incentives for the phase-out of natural gas. This is a very elaborate and detailed model. However, the extensiveness and level of detail of the model that make it so appealing also result in three main limitations with regard to the conclusions that can be drawn based on the model.

Firstly, because of its richness in variables and level of detail, the model has lost its transparency. To a certain extent, the model is a back-box model. It is unclear which options the model-uses has to run the model. In addition, the process from model input to model output cannot easily be traced; it is unclear in what way adjustments in the model settings work through in the model calculations. It is therefore unclear what model settings have effect on each other and if measures may have mitigating or enhancing effects on each other. Moreover, an extensive sensitivity analysis of the model is missing. It is therefore unclear how adjustments to model settings affect the model result.

Secondly, the model implies to generate valid model-outcomes at a neighbourhood level over 50 years. However, it is debateable that this level of detail can be established for such long optimization horizons and with such a complex optimization problem. At a national level, possible unwanted outliers are averaged out, but at a provincial or municipal level, these outliers can influence the relevance of the model outcomes.

Thirdly, the model has only be subject to very limited model validation steps. The PBL is aware of this and more extensive model validation is planned in 2018. However, model validation will be time-consuming due to the size and complexity of the model. The need for further model validation however, became evident while using the model. This shows in the following examples:

1) In the model, under standard model settings, the houses in the neighbourhoods of the city centre of Delft and Gouda will be connected to a district heating network based on geothermal heat. In reality it is unlikely that these houses will be connected to such a network, firstly because of the high costs of district heating infrastructure in old city-centres and secondly because of the low insulation level in these houses, which make low-temperature heating financially unattractive.
2) In the model, all oil-refineries in the area of the Europort and the Botlek have the same thermal capacities (125MW). However, in reality the capacity of these oil refineries strongly differs.
3) In the model, there is a waste incinerator located in Rotterdam South, while this waste incinerator was closed in 2010.

Besides, the model has three other limitations with regard to forecasting the development of district heating. Firstly, the calculation of the optimal design of a district heating infrastructure is a nonlinear optimization problem. To simplify the problem, the PBL has developed a logic for the development of district heating infrastructure. However, this logic has some major limitations. In the context of this thesis the most important limitation of this logic is that the model cannot deal with the expected benefits of the type of network the PZH expects i.e.: economies of scale, wide availability of heat throughout the province, main infrastructure that connects several distribution networks, multiple heat sources on one network.

Secondly, the model is a rule-based optimization model. It does not seek a global optimum. It merely adopts changes to the current situation when they provide a financial benefit. The order in which the options are evaluated is pre-determined. This is a strong simplification of the local trade-offs that can be made in the transition, as these trade-offs will likely include all alternatives for natural gas and not simply use the current natural gas based system as a reference. Moreover, the model results do not provide insights in the relative cost-reductions that are achieved through transitioning and the associated uncertainty margins. Thirdly, the model implies rational cost-minimising behaviour at a neighbourhood level, however, investments in residential energy systems are usually not the result of merely cost-minimizing behaviour (Wilson & Dowlatabadi, 2007).

In their reports, the PBL does not communicate the model limitations of Vesta/MAIS. The current communication of model results undermines the importance of human interpretation, based on critical evaluation of the data-inputs and model assumptions, which is necessary to value the model outcomes correctly. *"Models in science may be used for various purposes: organizing data, synthesizing information, and making predictions. However, the value of model predictions is undermined by their uncertainty, which arises primarily from the fact that our models of complex natural systems are always open. Models can never fully specify the systems that they describe, and therefore their predictions are always subject to uncertainties… this leads to a paradox: the more we strive for realism by incorporating as many as possible of the different processes and parameters that we believe to be operating in the system the more difficult it is for us to know if our test of the model are meaningful. "* (Oreskes, 2003, p. 13)

Perhaps this confidence in quantitative tools is because in the electricity and gas-markets decision-makers are comfortable basing their decisions on elaborate and well-tested models of existing infrastructure. However, an important difference between the gas and electricity market and the heat-market is the lack of a developed infrastructure. The large-scale development of heat infrastructure is associated with so many uncertainties, that it is difficult, if not impossible to develop a model that can simulate the development of the heat-transitions that is both valid and understandable. There are so many degrees of freedom when it comes to developing infrastructure that it is a non-linear and non-unique optimization problem. The decision-space needs to be simplified in a certain way to capture the problem in a model. In addition, these uncertainties can highly influence the model outcome. And actually, for district heating, there is only very limited literature on modelling district heating network growth, given the complexity of optimizing under so-many uncertainties and options (Haikarainen, Pettersson, & Saxén, 2013; Vesterlund, Toffolo, & Dahl, 2016).

Moreover, the PBL validates their model outcomes with the outcomes of the CEGOIA model of CE Delft, which is built based on similar model principles. When we project this line of confident communication and circle reasoning on validation on municipalities who seek guidance in their process of policymaking, we foresee a risk of ungrounded confidence in the predictability of the transition and resulting policy-making based on unknown-unknowns. Rather than hiding these uncertainties, knowledge institutes and consultants should make them explicit. When data that underlies policy decisions, is based on assumptions and uncertainty margins, policy makers should at least be able to evaluate them and decide how they want to deal with them.

The Vesta/MAIS model is a typical techno-economic model as described by Cherp et al. (2018) in the sense that it predicts transition pathways based on gradual changes in markets, energy flows and energy processes. This means that the resulting perspective on the heat transition, when solely based on the model results, is not sensitive to the social reality of the transition and cannot cope with radical technological changes.

Vesta/MAIS appears to have all relevant components of the transition in it, to back-up expectations. As such, the approach in a sense promises decision-makers that it provides a solid quantitative basis for policy-making. However, the analysis in this chapter has shown that this confidence is unjust. Not only do the model heuristics limit the predictive value of the model, the model itself is also typically unable to deal with technological innovations (Cherp et al., 2018). The approach wrongly projects a sense of predictability on the (local) transition outcome and is unclear about its limitations.

7.2.2 NEGOTIATED KNOWLEDGE

The Province of South Holland has commissioned several knowledge institutes (IF Technology, CE Delft, OverMorgen, etc.) to develop insights in demand and supply options. This knowledge development is very demand driven. The understanding of the development of district heating infrastructure is the result of a process of knowledge development in which the dominant actor coalition decides where additional knowledge is necessary. This is a typical political approach as described by Cherp et al. (2018) in the sense that a (political) process drives knowledge development and that the parties the Province interacts with constantly shape the frame of reference of the transition.

The knowledge available about the transition approach of the PZH is largely driven by an actor process, in which the included parties have individual interests and information needs. What we know about the approach of the PZH is negotiated knowledge: a form of knowledge that goes through a process of adjustment, consolidation and reconfiguration before it enters the policy process (Littoz-Monnet, 2017). While on the one hand negotiated knowledge may be tailored to the informational needs within the policy process, on the other hand negotiated knowledge may lack critical objective reflection. This is an on-going debate in political research: *"The panel asks how far the notion of scientific expertise in policy-making can be stretched, if it is increasingly asked to be reflective of outside considerations and political perceptions."* (Littoz-Monnet, 2017, p. 1). This means that it is necessary that the Province take an active role in safeguarding the balanced representation of interests in the transition and critically reflects on the results of the commissioned research.

When we look at the method the PZH deploys, we see that the approach provides limited options to (quantitatively) evaluate different dynamics in the heat transition, and the boundary conditions influencing these dynamics. There is limited insight in the effects of changing social, technological or market conditions, on the feasibility of the transition plans. However, there are currently no tools available that combine developing and testing heat transition plans at the scale of the Province. It is therefore necessary that the Province develop a very good understanding of the physical and technical limitations of the transition and the effects of interactions in the transition environment on these limitations.

7.3 UNCERTAINTIES OF THE FORECASTS

RQ: 1.3 What are the expected system designs based on the approach of the PBL and the PZH for developing district heating in South Holland?

The PBL and the PZH have very different ideas on how district heating in South Holland will develop over the next 12 to 32 years. They have different ideas on demand development, supply development and infrastructural design.

7.3.1 DEMAND

The approach of the PBL results in a situation in which on average only 6% of the households will switch to a district heating system. This indicates that based the selected market and policy conditions, for only 6% of the households it is both financially attractive and feasible to connect to a district-heating network that emerges based on the local demand for heat and locally available heat sources. For greenhouses and utility buildings, this is 12% and 32% respectively. Therefore, the emerging district heating networks will mostly connect utility buildings and greenhouses. Overall, the PBL expects that under current and expected market conditions, by 2030 only 14% of the heat demand will be supplied though district heating. The demand for heat varies per cluster between 5% and 34%. This shows that there are local areas in which district heating can be a cost-effective alternative for natural gas for a large group of consumers, and thus can substantially contribute to the transition. However, there are also regions in which district heating in only an attractive alternative for natural gas for a very small consumer group. More importantly, it shows that towards 2030 district heating will play a relatively modest role in the phase-out of natural gas.

The PBL does not only calculate the development of district heating systems, the Vesta/MAIS model considers the development of the heating sector as a whole. When we look at the result of the Vesta/MAIS model in the sensitivity analysis in appendix 2.1, in which we have evaluated the development of the heating sector under different scenarios for economic and demographic development, we see that the heat transition as a whole does not take-off. This means, that under the standard model settings of Vesta/MAIS, which represent the expected development of market conditions, without policy interventions, the transition objectives will not be achieved. Market interventions are necessary to stimulate the transition.

The PBL has calculated what the price of natural gas should be come to realize a full transition. To realize a full phase-out of natural gas, based on the market mechanisms in the Vesta/MAIS model, the gas-price should be increased stepwise from 0,60 €/m^3 in 2010 to 2,25 €/m^3 in 2050 (Planbureau voor de Leefomgeving, 2017b). According to the model, this results in demand reductions of approximately 50%. Moreover, in South Holland it results in a very high development of geothermal heat sources and small-scale low-temperature district heating networks. This shows that the PBL expects that it is necessary to make rather extreme changes in consumer energy prices to achieve the phase-out of natural gas.

The approach of the PZH results in a situation in which the expected development of the demand for heat is highly uncertain, as it varies between 25% and 80%. However, the development of demand is expected to be equal amongst the different consumer groups. The availability of heat is expected to be higher than in the approach of the PBL, due to the heat infrastructure. Moreover, economies of scale should result in lower investment costs and variable costs, and make district heating systems financially more attractive than in the approach of the PZH. However, the effect of economies of scale have not been quantified by the PZH. It is therefore unknown what exactly the potential financial benefits of large-scale planned district heating infrastructure are. Additionally, it is unclear what drivers or financial pivoting points are for the different consumer groups to switch to district heating infrastructure. Therefore, it is not possible to calculate what the (financial) benefits of large-scale infrastructure should be, to realize these higher market penetration rates. The PZH acknowledges that it does not know how the demand-side of district heating systems will develop, and what the main drivers are for this development. However, this makes it very difficult to evaluate the feasibility of the envisioned system design.

For both approaches, it is necessary to develop a better understanding of the drivers for residential energy investments. Understanding the dynamics behind investment behaviour is a first step in making better estimates about the demand-side development of district heating systems, in this transition where the decision-mandate lies with the individual resident. These insights can be used to better evaluate the envisioned transition outcomes under demand uncertainty.

7.3.2 SUPPLY

The approach of the PZH and the approach of the PBL also result in a different set of available heat sources. In section 4.4.2 we have shown that based on a study by the PBL and CE Delft, we assume that there is approximately 3899 MW of residual heat available in 2030. The heat sources is scattered over the province, however, the centre of gravity of the available heat lies in the Rotterdam Harbour, where there are hardly any non-industrial heat consumers. The development of primary district heating infrastructure will dictate to what extend this heat will be available for use throughout the province.

In the scenario based on **the approach of the PBL** the available production capacity is 2377 MW. Approximately 50 MW is available from geothermal heat sources that currently exist or will be developed towards 2030. This means that 2327 MW out of the 3999 MW available residual heat lies within the scope of the primary district heating infrastructure. This also means that there is potentially 1572 MW additional residual heat available that can only become available through additional infrastructural investments. However, when comparing the available supply to the demand for district heating (396 MW) and to the total heat demand (1984 MW), this may not be necessary.

In the scenarios based on **the approach of the PZH** the available production capacity is lies between 4172 MW and 4484 MW, depending on the expected development of geothermal heat. This large difference stems from the route of the primary heat infrastructure, which connects the available heat in Rotterdam Harbour. Moreover, the PZH expects a 5 to 12 times higher development of geothermal heat. The comparison of the dataset of the PBL with the datasets of CE Delft, Gasunie and Port of Rotterdam, in section 4.5 shows that the availability of residual heat towards 2030 and beyond is rather uncertain. The estimations of available residual heat for all sectors and locations vary strongly. Moreover, we see that the datasets are incomplete, as only typically high-temperature residual heat sources are described. Especially towards 4th generation district heating networks, also low-temperature heat sources are relevant.

The data from Gasunie and the Port of Rotterdam is not transparent, therefore it is unclear from where the differences between estimations originate. In addition, the PBL and CE Delft adopt very different principles to estimate the availability of residual heat. The PBL based the estimations for available residual heat on estimations for electrical and thermal efficiencies and CE Delft based the estimations for available residual heat on CO_2 emissions. It is therefore necessary to develop a better understanding of what type of residual heat sources are relevant for the heat transition, given the different potential heat regimes for district heating. Moreover, it is necessary to start a discussion about how insightful estimations of residual heat sources over time can be made.

7.4 EFFECT OF UNCERTAINTIES ON POLICY TARGET

RQ 1.4: What are the differences between the system designs for district heating infrastructure in South Holland with regard to CO2 emissions, overall investment costs and costs of CO2 abatement?

In this section, we will evaluate the effect of the uncertainty about the development of heat demand and supply on the policy target of cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050. In chapter 6, we have estimated the total investment costs and the investment costs per MW system capacity for each of the scenarios. Table 41 shows these estimations. The model results. This overview shows a trade-off between the cost-effectiveness of CO_2 abatement and the relative CO_2 abatement per supplied MWh of heat through district heating.

Table 39 Overview of main model results

	Total investment costs (mln. €)	Relative investment costs (mln. € /MW)	Total annual CO_2 abatement (kton CO_2)	Relative CO_2 abatement in ton CO_2 emissions (kg CO_2/MWh)	Cost effectiveness CO_2 abatement (kg/€)
Distributed	€ 885	€ 2,31	498	143	16
Limited	€ 2.407	€ 3,03	1070	154	13
Unforeseen	€ 4.142	€ 2,61	1864	134	14
Abundance	€ 4.725	€ 2,98	2203	158	14

However, in chapter 4 and 5, we have seen that uncertain data inputs can influence the model results. In this section, we will discuss the model results in relation to the uncertainties we have identified in chapter four and five and the effects of these uncertainties on the model outcomes. Currently, we do not know exactly what reasonable uncertainty margin are. While additional research is necessary to establish these uncertainty margins, based on the discussion of the uncertainty ranges on the model inputs in this thesis, we think that 10% uncertainty margin is a very modest estimate. When we combine the data we have gathered on the approach of the PBL and the approach of the PZH with the alternative datasets for demand and supply we have discussed in 4.5 and the description of district heating systems in section 4.1, we find much larger uncertainty margins. These uncertainty margins are shown in table 42. In this section we will evaluate what the effect of an uncertainty margin of 10% on all the relevant model inputs will be on the conclusions we can draw about the model result.

Table 40 Uncertainty margins for developing district heating in South Holland

	Minimum estimates	Maximum estimates
Demand connected to DH	14%	80%
Demand reduction towards 2030	0%	2% annually
Availability of residual heat	-78%	+37%
Availablity of geothermal heat (MW)	50	600
Detour factor	1,3	1,7

7.4.1 CO_2 EMISSIONS

In chapter 4, we have seen that the CO_2 emissions are sensitive to: the demand per cluster, the available residual heat per cluster, the available geothermal heat per cluster and the pipeline capacity between the clusters. When we assume that the uncertainty range on these input parameters is 10%, the CO_2 emissions we estimate using the model can range between -25,3% and +25,4% of the model output. Figure 42 shows the resulting margins on the CO_2 emissions from district heating. The figure shows that there are no absolute differences between the ranges of CO_2 emissions. Again, this means, that if indeed 10% is a viable uncertainty margin for all of these inputs, we cannot say anything about absolute differences between the CO_2 emissions from district heating in the different scenarios.

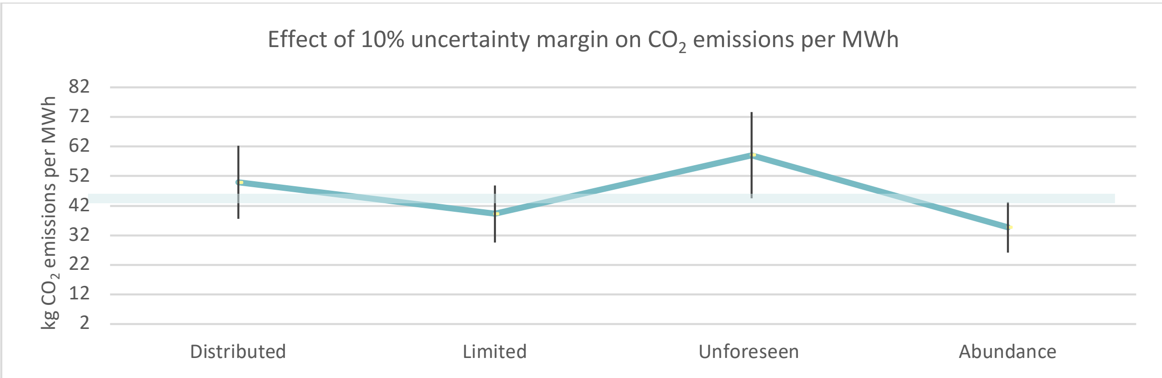


Figure 46 Effect of 10% uncertainty margin on CO_2 emissions per MWh

7.4.2 INVESTMENT COSTS

In chapter 5, we have seen that the investment costs are sensitive to: the density of the demand, the total heat demand, the detour factor, the length of the primary heat transport network, the capacity of the primary heat transport network and, the total capacity of geothermal heat sources. We have performed a sensitivity analysis to gain insights in the effects of the uncertainty of these inputs on the model outcome. Figure 46 shows the effect of 10% change in the estimations of these factors on the investment costs. When we assume that the uncertainty range on all input parameters is 10%, the effects of uncertainties on the total investment costs lie between -20% and +19,8%. Moreover, the uncertainty range on the investment costs per MW lies between -28% and +8%. Figure 47 shows the ranges of potential investment costs per MW in mln. €/MW.

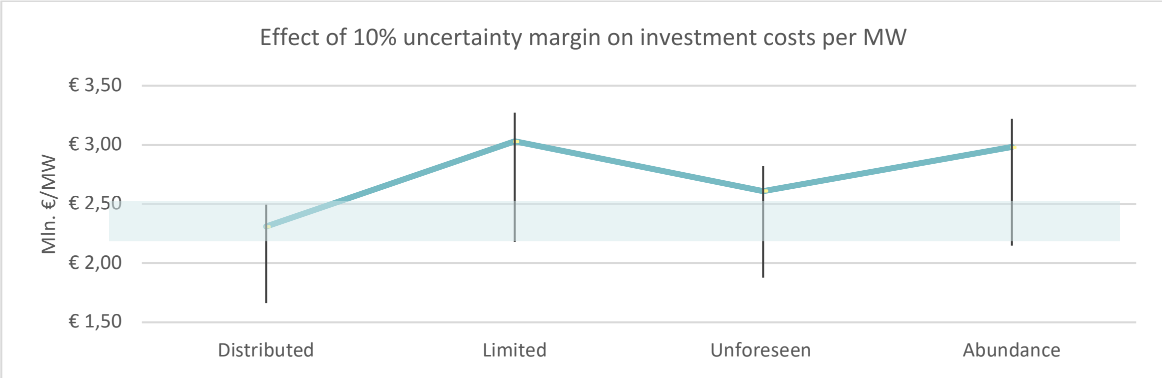


Figure 47 Effect of 10% uncertainty margin on uncertain data-inputs on investment costs scaled to the system capacity in mln. €/MW

7.4.3 COST EFFECTIVE CO_2 ABATEMENT

Figure 48 shows that when we assume that the uncertainty margin on all uncertain design inputs is 10%, the margins for the estimations of the investment costs per MW system capacity overlap. This means, that if indeed 10% is a viable uncertainty margin for all of these inputs, we cannot say anything about absolute differences between the investment costs per MW of the different scenarios. This means that the estimations of the scenarios with regard to the investment costs for CO_2 abatement are highly uncertain for all four scenarios. When we calculate the CO_2 abatement that can be achieved for every euro invested, over a period of 30 years, given the uncertainty margins we have identified on CO_2 abatement and investment costs in section 6.5.1 and 6.5.2, we find very large uncertainty margins (figure 48). Depending on the scenario, the CO_2 emissions that are avoided for each euro invested can deviate between 53% and 148% of the outcome of the scenario analysis.

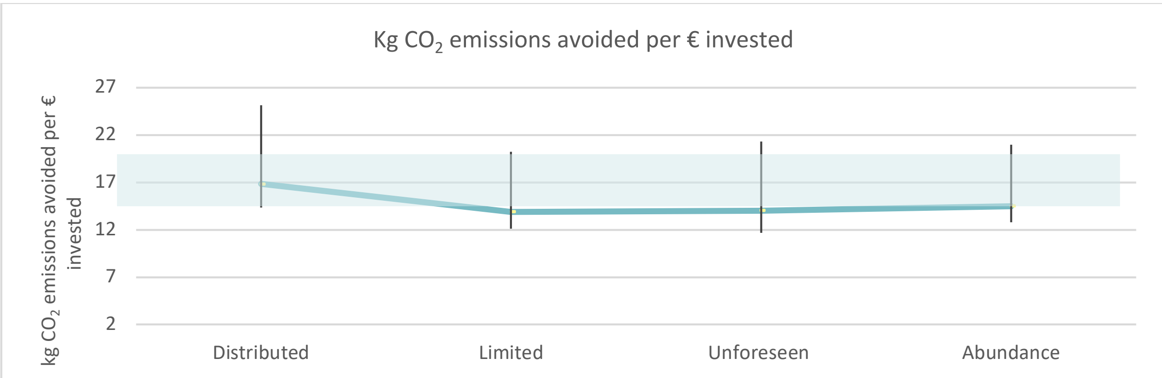


Figure 48 Kg CO_2 emissions avoided per € invested given the uncertainty margins on the investment costs and the CO_2 emissions

We see that based on the researched scenarios, the scenario of the PBL leads to the most cost-effective CO_2 abatement, where the scenarios of the PZH result in the highest relative and absolute CO_2 abatement. However, throughout the study, we have seen that many of the model inputs we have used are highly uncertain. In this section, we have seen that the identified differences between the scenarios do not hold when we evaluate them under uncertainty margins that seem relatively modest in comparison to the uncertainty margins observed throughout the study. The calculated model results heavily depend on the accuracy of the estimations with regard to the demand, supply and their resulting infrastructure design. Moreover, the relative advantages and disadvantages that we have identified between the scenarios highly depend on the extent to which engineers are able to design the infrastructure for the right groups of consumers and suppliers.

7.5 DISCUSSION OF RISKS AND MITIGATION MEASURES

In 7.3.1 to 7.1.3 we have discussed the approach of the PBL and the approach of the PZH for the development of district heating infrastructure, to identify risks associated with adopting these approaches.

7.5.1 PROCESS

A main risk associated with both transition approaches, relates to the extent to which municipalities are able to activate or convince residents. Neither of the approaches seems to have mechanisms through which the desired behaviour of residents can be guaranteed, while the success of both approaches heavily depend on this behaviour. It is necessary to develop insights in the conditions under, and the extent to which residents are willing and able to take part in district heating. In order to make better estimations about the development of the demand. In addition, to design transition processes that fit with these needs.

7.5.1 FORECASTS

Both forecasts suffer from knowledge gaps. The forecasts lack insights in the drivers residents have to participate in the transition. There is no consensus about the availability of heat sources towards 2030 nor the way in which these estimations should be made. Moreover, there is no insight in the availability of low-temperature heat sources towards 2030.

Main risks associated with the forecasts of the Vesta/MAIS model relate to the confident communication of the model results, while the discussion of the model shows that this confidence is unjust. In light of the overall transition, the forecast of the PBL shows a limited transition towards 2030. National policy advice that is solely based on the Vesta/MAIS model will likely include a significant increase of the gas price to accelerate the transition. However, given the limitations of the Vesta/MAIS model we have discussed in 7.2.1 this increase may not have the desired effect.

To overcome the risks associates with the use of the Vesta/MAIS model, it is necessary that policy makers are fully aware of the model limitations and uncertainty margins and take time to interpret the results correctly. To do this it is necessary that a thorough sensitivity analysis is performed on the model, which shows how variables interact. Moreover, especially when the model is used in a local or regional setting, it is necessary to check if model inputs and assumptions fit with the local situation. A scenario analysis outside the scope of the model, that includes radical technological innovations, alternative methods for infrastructure development and the social dynamics of the heat transition can provide complementary insights to the model runs.

The forecasts of the PZH show a much larger development of district heating; however, these estimations also show large uncertainty margins that reflect the identified knowledge gaps. Main risks associated with the process of knowledge development of the PBL are that it is sensitive to unbalanced representation of interests and may lack of critical reflection. Moreover, the separate studies provide limited insights in the dynamics of the transition and the interaction of the changes with the environment. To overcome the risks associated with this way of knowledge development, the PZH can encourage studies that provide insights in transition dynamics and the underlying assumptions, rather than definite (quantitative) answers. Additionally, they can let an independent party troubleshoot on the acquired knowledge.

7.5.3 OVERVIEW

The identified risks and mitigation measures are summarized in table 39 and 40. The risks relate to the transition approach, and the forecasting method and the knowledge gaps we have identified.

Table 41 Risks of the approach of the PZH for the heat transition at a municipal level

	Context	Risk	Result	Mitigation measure
Process	The transition is plan driven.	Unforeseen changes in the environment.	The transition may not take-off.	(Independent) scenario analysis.
		Residents may not accept the transition plans.	The transition may not take-off.	Develop bottom-up insights in relevant demand-side decision-criteria.
	The infrastructure requires high up-front investments.	The development of heat demand and supply are highly uncertain.	Impasse when parties are unable or unwilling to take these investment risks.	Develop bottom-up insights in relevant demand-side decision-criteria. Develop insights in dynamics behind development of heat demand.
		Unbalanced representation of interests in the transition process.	Unfair transition outcome.	Inclusion of relevant local parties in policymaking.
Forecasting method	The PZH adopts a political perspective on energy transitions.	Poor representation of material factors.	Transition policy based on incomplete information.	Develop better insights in the physical impact of the transition on the environment, and the (material) limitations of the environment on the transition.
		Limited insights in cohesion between the results of different quantitative studies.		Encourage studies that provide insights in transition dynamics and the underlying assumptions, rather than definite (quantitative) answers.
		Negotiated knowledge lacks critical reflection.	Circle reasoning and self-validation.	Let an independent party troubleshoot on negotiated knowledge.

Table 42 Risks of the approach of the PBL for the heat transition at a municipal level

	Context	Risk	Result	Mitigation measure
Process	The focus of the transition is local.	Investment decisions are made based on current local demand and supply.	The investment decisions may be inefficient in the light of the overall transition.	Alignment of transition initiatives and inclusion of scenario analysis in investment decision. Better insights in dynamics behind development of heat demand.
	The transition is market driven.	The municipality has no mandate to align transition plans.	The transition may be inefficient.	Bottom-up insights in relevant decision-criteria. Clear communication about potential inefficiencies.
		Residents and companies may not experience the right incentives to transition.	The transition may not take-off.	Develop bottom-up insights in relevant demand-side decision-criteria.
		The end-state of the transition is unclear.		Clear communication about full transition objective.
	The PBL adopts a techno-economic perspective	The forecasts are not sensitive to the social reality of the transition.	There is a limited understanding of the adoption of transition policy by residents.	Develop bottom-up insights in relevant demand-side decision-criteria.
Forecasting method	Forecasts of the Vesta/MAIS model do not include transition divers beyond cost-minimization.		Overestimation of the share of consumers that is willing and able to participate in the transition.	Human interpretation of model results. Develop bottom-up insights in relevant demand-side decision-criteria.
	The Vesta/MAIS model cannot cope with radical technological innovations.	Technological innovations are excluded from the analysis.	Model-based policy is naïve towards radical technological innovations.	Scenario analysis outside the scope of the model. Human interpretation of model results.
	The Vesta/MAIS model is based on assumptions.	The effect of the model assumptions on modelled transition outcome is unclear.	Municipalities develop an ungrounded confidence in the predictability of the transition and resulting policy based on unknown-unknowns.	Thorough sensitivity analysis. Clear communication about model limitations and uncertainty margins.
		The model is unable to cope with alternative methods for district heating development.	Municipalities develop a limited view on the development of district heating infrastructure.	Clear communication about model limitations. Human interpretation of model results.
	The Vesta/MAIS model inputs show validity issues.	Model results are calculated based on faulty data inputs.	Model outliers may be averaged out at a national scale, but are highly relevant when used at a local scale.	Thorough check if model inputs and assumptions fit with the local situation. Human interpretation of model results.

7.6 CONCLUSION

In this chapter, we have identified risks that relate to the process and the forecasting method. Moreover, we have shown that the knowledge gaps we encountered throughout the thesis pose risks for both approaches. These risks are relevant for the municipal, regional and national transition objectives, as the success of the transition at a regional and national level, depend on the municipal transition plans and the ability of municipalities to execute these plans. While the approaches for developing district heating are different, the risks we have identified are relatively similar. They adhere to the insensitivity of the approaches to the mandate in the transition, the limited, opaque and disagreeing insights in demand and supply developments, and the confident communication of model results (especially Vesta/MAIS) in a highly unpredictable transition environment.

To mitigate the identified risks we propose: further knowledge development about (low-temperature) heat sources, open communication about the limits an uncertainty margin of quantitative forecasts, critical reflection on or human interpretation of data results, scenario analysis for inherent uncertainties (economic development, radical technological progress, political climate, public opinion, international energy prices, etc.), inclusion of residents in the policy process to develop bottom-up insights in transition needs and a changing focus from static to dynamic transition insights.

8.

DISCUSSION AND CONCLUSION

In this second section of the thesis, we have researched the relevant differences between the two regional transition approaches, with regard to the implementation of district heating at a municipal level for realizing cost-efficient CO_2 abatement. In this chapter, the research results are summarized and discussed. This starts with a recap of the research problem (8.1), followed by a discussion of the research approach (8.2). In 8.3 we answer the main research question. We end the chapter with policy recommendations (8.4), and recommendations for future research (8.5).

What are relevant differences between the two regional transition approaches, with regard to the implementation of district heating at a municipal level for realizing cost-efficient CO_2 abatement?

8.1 RECAP OF RESEARCH PROBLEM

The research objective of this first part of the thesis was to identify the advantages and disadvantages the approach of the PBL and the approach of the PZH for realizing district heating, with respect to cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. The social relevance of answering this research question lies in the task municipalities will face in developing environmental plans towards 2021, in which they have to specify in which districts natural gas will be phased out, and what technology will be used to replace the current gas-based heating system. Municipalities face complex policy decisions with regard to the approach they want to deploy in this transition process. Municipalities in South Holland are guided by the approach of the PBL, which is local, and market driven, and the approach of the PZH, which is regional and plan driven, for realizing district heating. However, there is little insight in the differences between the transition approaches and potential outcomes. Municipalities are in need of better insights in the trade-offs they are facing. In this thesis, we have evaluated the two regional approaches for the phase-out of natural gas in terms of their conceptual differences, their methods to gain quantitative insights and their potential implications on the aforementioned policy target.

8.2 DISCUSSION

To evaluate the two approaches, we have initially embraced them. We have performed a grey literature search, and we have consulted with the PBL and the PZH to understand how they envision the heat transition and what they think is necessary to realize this. In chapter 3 we describe how the PBL and the PZH view the transition, what methods they use to forecast transition outcomes and how their relative approaches will contribute to the phase-out of natural gas.

Secondly, we have evaluated potential transition outcomes following these two approaches in the light of the overarching national policy objective of cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. To gain these insights, we have adapted an existing model of CE Delft, which can calculate the investment costs and fixed costs of district heating infrastructure. We have the removed spatial variation in network design for different consumer groups from the model, as this detailed information is not available. Moreover, we have added the costs for heat storage. The resulting model provides valid initial estimations for the investment costs, without requiring detailed information about the heat demand. The model has pointed out that the investment costs of district heating infrastructure in relation to the total system capacity are sensitive to the following factors: the density of the demand, the total heat demand, the detour factor, the length of the primary heat transport network, the capacity of the primary heat transport network and, the total capacity of geothermal heat sources. These factors all relate to the spatial development of supply and demand for district heating. Important limitations of this model are:

- the simplifications with regard to the spatial outline of the network for different consumer groups,
- the limited validity of the formula for the investment costs in main heat transport pipelines that exceed 125MW,
- the limited insights in the potential ranges of the investment costs for different costs components and the effect on the margins for the total expected investment costs and,
- the necessity of a feasibility check on the energy balance within each cluster.

Moreover, in this planned development of infrastructure, initial investments in the primary heat infrastructure that facilitate network growth precede demand, and financial constructions are necessary that can support the initial over dimensioning of the heat infrastructure and mitigate investment risks. The timing of investments and returns is not included in the model.

Furthermore, we have developed a dispatch model that can calculate the performance of a district heating system in terms of CO_2 abatement and marginal costs of heat production. This model was used instead of the NEN7025 Norm, which is the current standard for calculating the performance of district heating infrastructure in terms of CO_2 emissions. Other than the NEN7025 norm, the dispatch model includes temporal and spatial mismatches between supply and demand due to production constraints (ramping constraint, maintenance etc.), consumption patterns (weather conditions, behaviour, building type, hot water demands), network constraints (max. capacity, losses, min. flow). The dispatch model however, does not include the effects of the network behaviour (temperature losses, pressure changes and time-delays). Moreover, the dispatch model includes heat storage, which can reduce the use of peak load plants. The sensitivity analysis has pointed out that the model is sensitive to the heat demand for district heat and the availability of geothermal heat sources. This has provided insights in the relative advantages and disadvantages of the envisioned transition outcomes in relation to the policy target of cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. Main limitations of the model are, the uncertainty with regard to the shape of the load-duration curve, uncertainty with regard to the data-inputs (total demand and supply) and the lack of time-delays in the network.

Thirdly, we have reflected on the approach of the PBL and the PZH in light of the uncertainties and risks we have encountered throughout the research. To support this analysis, we have placed the approaches in the framework the three perspectives on national energy transitions by Cherp et al. (2018). This supported us to critically reflect on the forecasting methods. Finally, we have proposed mitigation measures for the identified risks. This resulted in general recommendations for improving the process of developing national, regional and local heat transition policy.

8.3 CONCLUSION

What are relevant differences between the two regional transition approaches, with regard to the implementation of district heating at a municipal level for realizing cost-efficient CO_2 abatement?

The approach of the PBL and the PZH for the development of district heating infrastructure differ with regard to the concepts underlying the transition, the methods the organizations deploy to develop foresights and their transition vision.

The PBL adopts a local market driven perspective on energy transitions, forecasts depend on the Vesta/MAIS model. The PBL expects that this approach will result in the distributed development of small-scale district heating networks. The heat in these networks will predominantly come from existing waste-incinerators in Rotterdam and Dordrecht and the gas-fired electricity plants in the region of Rotterdam North. Under current market conditions, approximately 14% of the heat demand can cost-effectively be supplied through district heating infrastructure. In 2030, there is an uneven impact of the transition amongst consumer groups and regions. 32% Of the greenhouses is connected to district heating, followed by 12% utility buildings and finally only 6% of the residential heat consumers is connected to district heating. Moreover, the transition will have the largest impact in the region of Lansingerland, where 34% of the consumers will be connected to district heating and the smallest impact in the regions of The Hague and Dordrecht, where respectively 5% and 6% of the consumers is connected to district heating. These district heating networks require a total investment of approximately 885 million euro and result in approximately 74% CO_2 abatement. Over a period of 30 years, this investment will result in approximately 15 Mton of avoided CO_2 emissions. For each euro invested, approximately 16 kg of CO_2 emissions can be avoided.

However, the approach of the PBL depends on the market uptake of the transition. The model based on the approach only uses cost-minimization (under perfect information) as a decision driver. This is a very limited view on (residential) energy investments, which can result in overestimations of actual transition behaviour. Yet, the transition modelled in Vesta/MAIS does not take-off. By 2030, 86% of the demand still depends on natural gas. To realize a full phase-out, the PBL expects that the gas price needs to be increased from 0,60 €/m^3 in 2010 to 2,25 €/m^3 in 2050. This will result in approximately 50% demand reduction and a near complete phase-out of natural gas. Given the limitations of the model we have discussed in this thesis, it is doubtful that this increase in the gas-price will have the anticipated effect. However, the model limitations and uncertainties in the model results are not communicated by the PBL. Therefore, the main risk associated with the approach of the PBL lies in the communicated predictive value of the model and the related overconfidence in financial incentives on the transition outcome, resulting in high energy prices and an impasse for the actual transition.

The PZH adopts a regional, plan driven perspective on energy transitions, the approach is plan driven and the forecasts depend on negotiated knowledge. The PBL expects that this approach will result in a large main heat transport infrastructure that will make heat from the Rotterdam harbour available throughout South Holland. This heat complements the locally available heat sources. However, realizing the infrastructure requires upfront demand commitments. The PZH is uncertain with regard to the development of demand and available heat of geothermal heat sources, which will influence the final system design. The PZH expects that 25% to 80% of the heat consumers in selected regions in South Holland will connect to district heating. A quick scan of the available supply options and the necessary pipeline capacities to supply heat to the heat consumers in South Holland showed that connecting 80% of the consumers to district heating requires pipeline capacities that seem infeasible in comparison to the currently existing pipelines and pipeline standards. Therefore, we have only looked at scenarios in which a maximum of 50% of the consumers connects to district heating.

The PZH does not distinguish between consumer groups. It expects that district heating will become equally attractive for houses, greenhouses and utility buildings. Moreover, the PZH expects that the development of geothermal heat sources will take off and that there will be approximately 285-600 MW of geothermal heat available. The heat in the district heating system will predominantly come from residual heat from the oil industry in the Rotterdam Harbour and geothermal heat sources. The district heating networks require between 2407 million euro and 4725 million euro of investments and result in 70%-82% CO_2 abatement. Where the CO_2 abatement mostly depends on the availability of zero-emission heat sources in comparison to the heat demand. The investment costs largely depend on the capacity of the system and the number of geothermal heat sources that is connected. Over a period of 30 years, this investment will result in approximately 32-66 Mton of avoided CO_2 emissions. For each euro invested, approximately 13-14 kg of CO_2 emissions can be avoided. However, in this approach initial investments in the primary heat infrastructure that facilitate network growth precede demand, and financial constructions are necessary that can support the initial over dimensioning of the heat infrastructure and mitigate investment risks.

Based on this comparison of the approaches, a trade-off appears between cost-effective CO_2 abatement, and maximizing the overall reduction of CO_2 emissions. In which the scenarios of the PZH in general result in higher levels of CO_2 abatement and the scenario of the PBL is more cost-effective. Additionally, in the light of the full phase-out of natural gas the approach of the PZH appears to provide better opportunities to realize large-scale district heating. The PZH expects that this is a cost-effective alternative for the current gas-based system. This is supported by the analysis, which shows heat supply costs of €36/ MWh in the scenario of the PBL and heat supply costs of €38-42/ MWh in the scenarios of the PZH. While the costs are higher, they do not nearly compare to the 2,25€/m^3 or 230 €/MWh the PBL expects necessary for a full phase-out of natural gas.

However, the approach of the PZH depends on the ability of the Heat Alliance to develop accurate predictions of the position of large-scale district heating infrastructure in a natural gas-free heating system. Moreover, it depends on the extent to which municipalities and residents are willing to conform to these plans. Currently, these estimates show large uncertainty margins. Moreover, there is limited insight in the dynamics behind the estimates and how inherent uncertainties affect the estimations. To facilitate a full transition, it may seem attractive to over-estimate pipeline capacities to facilitate maximum expected demand levels. However, this both deteriorates business cases and potentially results in sub-optimal network operation. The main risks associated with this approach is therefore an impasse in the transition as a result of inabilities of heat companies to develop solid business cases for primary district heating infrastructure, and municipalities who refrain from initiating processes for developing local sources because of the promise of the advantages of the main heat infrastructure.

8.4 POLICY RECOMMENDATIONS

We have started this thesis with the task municipalities face to select a technology for the phase-out of natural gas for each district in which natural gas will be phased out up to 2030, by 2021. Municipalities need to make a selection of districts and technologies based on technical, physical, financial and social opportunities. This selection should both result in high levels of CO_2 abatement, and facilitate a full phase-out of natural gas. In this study, we have seen that the vision of the PZH to develop a main heat infrastructure appears to facilitate the scale-up in district heating from 14% to 50% of the current demand relatively cost-effectively. The total costs of heat supply in the scenarios of the PZH lie 2-6€/MWH higher than the calculated scenario of the PBL, however they do not compare to the additional 150 €/MWh the PBL expects necessary for a full phase-out of natural gas. However, this requires smart initial investments that facilitate this scale-up, and financial constructions that can support the initial over dimensioning of the heat infrastructure and mitigate investment risks.

As we have discussed in the introduction, municipalities currently use heat atlases as an important tool to support the development of environmental plans in which they have to point out in which districts natural gas will be phased out by 2030 and what technology they expect will replace the current natural gas based heating system. These heat atlases calculate the technical and financial feasibility of district heating and other technologies per area, select, and communicate a preferred technology per neighbourhood. As such, these atlases imply certain conditions under which district heat is available. The CEGOIA model of CE Delft, the Vesta/MAIS model of the PBL and the WTA model of OverMorgen are amongst the tools that are being used to develop these atlases.

We know that the CEGOIA model of CE Delft and the Vesta/MAIS model of the PBL have similar outcomes with regard to the potential of district heating. However, these models also have similar model heuristics for the development of heat infrastructure. Moreover, we know that OverMorgen seems to estimate a higher potential for district heat. However, it is unclear where these differences come from and how they relate to the approaches we have discussed in this thesis. The communicative value of these atlases is very strong. In addition, the atlases are very rectilinear with regard to the preferential heat solutions in each district. Especially in this new and vague and complex task municipalities' face, regarding the formulation of transition plans, they provide guidance

However, given the analysis we have performed in this thesis we should re-evaluate the current position of heat atlases in the policy process. The models are a simplified representation of reality and there are so many degrees of freedom when it comes to developing infrastructure that it is a non-linear and non-unique optimization problem. Policy makers should accept that the heat transition is too complex to be fully captured in model-based predictions. Instead, they should become attentive towards understanding the assumptions and the uncertainties that underlie the model results they are faced with, and interpret them in light of the local and regional or national transition objectives.

To support municipal policymaking, I would suggest removing all model heuristics that determine the potential for district heating based on network growth. Instead, I would suggest communicating relevant trade-offs between the alternatives, including but not limited to cost-estimates, and uncertainty margins for each technology per neighbourhood. After which for district heating technical feasibility can be assessed and where relevant a trade-off can be made be between dimensioning to current local demand, and thus controlling investment risk, but also potentially impeding (cost-effective) network growth, or dimensioning to future expected demand, and accepting the risks of over-dimensioning. Here lies a task for governmental organizations, let it be national, provincial or municipal, to co-evaluate the local advantages and disadvantages of both approaches and to potentially mitigate the investment risk associated with the plan based approach.

8.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Throughout the thesis, we have encountered several problems that may impede the success of the heat transition, which require additional research. These are:

- How can municipalities better incorporate uncertainties with regard to the willingness and ability of residents to participate in the heat transition in their policy process?
- What share of the residents is willing and able to participate in the heat transition?
- Under what conditions are residents willing and able to participate in the heat transition?
- How can municipalities incorporate the decision mandate of residents in their policy processes?
- How can policy makers develop better insights in the coherent dynamics behind the heat transition, given that the optimization problem is too complex to capture in a quantitative model?
- What is the effect of the time inconsistency between investments and returns on investment decisions for primary heat infrastructure in the planned development of district heating infrastructure?
- What is the effect of the time-delay between demand-signals and supply responses on the optimal dispatch schedule?
- What is the potential for low-temperature residual heat sources in South Holland?
- Why are the estimates for the availability of residual heat sources in South Holland towards 2030 so different?
- What is the effect of the discussed inherent uncertainties on the feasibility of the transition plans?

SECTION 3
SCIENCE COMMUNICATION RESEARCH

How can municipalities gain insight in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level?

One of the main identified uncertainties for the phase-out of natural gas is that of public acceptance of the transition, and the dependence of the realization of the transition on the willingness and ability of individual residents to participate in the transition. "The environmental challenges that confront society are unprecedented and staggering in their scope, pace and complexity. Unless we reframe and examine them through a social lens, societal responses will be too little, too late, and potentially blind to negative consequences."(Hackmann, Moser, & St. Clair, 2014, p. 653). Therefore, in the third section of the thesis, we will evaluate a method through which municipalities can gain insights in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level.

9.

PUBLIC SUPPORT IN ENERGY TRANSITIONS

How can the design of decision-and-communication processes contribute to the public acceptance of the heat transition?

Realizing public support for energy transitions is a complex topic, which is in need of better understanding (Platform for Energy Research in the Socio-economic Nexus (PERSON), 2014). *Literature indicates that participatory decision-making and collective learning and education are two methods through which public support for energy transitions can be realized* (Rotmans et al., 2001). *This chapter explores the relation between a process of participatory decision-making, collective learning and education, and public acceptance. In 9.1 the necessity of public acceptance in the heat transition is explored. In 9.2, a structured literature review is performed to further deepen the understanding of the relation between participatory decision-making and collective learning and education and public acceptance in the context of the heat transition. Based on this literature review, a theoretic framework on participatory decision-making and collective learning and education for realizing public support in energy transitions is developed (9.3). This framework functions as a guideline for the definition of the Q-set in chapter 10. Section 9.4 contains a conclusion about important design considerations for a process of participatory decision-making and collective learning and education to achieve public acceptance on the heat transition.*

9.1 PUBLIC ACCEPTANCE OF THE HEAT TRANSITION

This third part of the research adopts transition management as a theoretical framework. Transition management is based on the idea that sustainable development requires changes in socio-technical systems and wider societal change – in beliefs, values and governance that co-evolve with technology changes. Transition management is a governance approach that aims to facilitate and stimulate energy transitions and it has a focus on the socio-technical aspects of transitions. Transition management provides a good framework for researching public acceptance in the context of the heat transition, as it assumes distributed power and multiple different actors that shape the transition. As such, it places residents at the heart of the transition, which fits with their current legal status within the transition.

From a transition management perspective, a district heating network is a ‘’*socio-technical system, comprised of more than just pipelines, fuels, and engineering equipment. Markets, institutions, consumer behaviours and other factors affect the way technical infrastructures are constructed and operated.*’’(Keirstead et al., 2012, p. 3848). Moreover, the development of a district heating system is perceived as a transition of the energy system, as the technological change demands a change of infrastructure, behaviour and formal and informal institutions. *“A transition can be defined as a gradual, continuous process of change where the structural character of a society (or a complex sub-system of society) transforms. Transitions are not uniform, and nor is the transition process deterministic: there are large differences in the scale of change and the period over which it occurs. Transitions involve a range of possible development paths, whose direction, scale and speed government policy can influence, but never entirely control.”* (Rotmans et al., 2001, p. 16). And “*The environmental challenges that confront society are unprecedented and staggering in their scope, pace and complexity. Unless we reframe and examine them through a social lens, societal responses will be too little, too late, and potentially blind to negative consequences.*”(Hackmann, Moser, & St. Clair, 2014, p. 653) In the process of energy transitions, developing a shared vision alongside building social networks and enabling learning processes are necessary (Geels, 2002; Rotmans et al., 2001). Moreover, participatory decision-making and collective learning and education are two methods through which public support for energy transitions can be realized *(Rotmans et al., 2001)*.

This means that from this perspective, to achieve public acceptance and facilitate public action for the phase-out of natural gas, it is necessary to organize a process in which relevant stakeholders, such as the municipality, residents and relevant commercial parties interact and collaborate to develop a shared vision of the transition. In this process, they should be learning partners and participate in decision-making processes. For the remainder of this thesis, we will refer to this as a communication-and-decision making process. Moreover, it is necessary to accept that this process will also shape the direction of the transition.

9.1.1 TWO LEVELS OF PUBLIC ACCEPTANCE

In section one and two of this thesis, we focussed on describing and comparing the two approaches for developing district heating. In this third section, the focus initially is broader, the focus lies on the whole heat transition. The focus is broadened because the development of district heating is inseparable from the transition as a whole. We assume that it is necessary to achieve public acceptance for the phase-out of natural gas, as a prerequisite for public acceptance of district heating, independent of the approach. This assumption is stooled on the concept of distributed power amongst companies, residents and governments in the transition. This distributed power implies freedom of choice, which is also confirmed through the legal mandate of residents. Public acceptance therefore needs to be established at two levels, firstly at the level of the transition as a whole and secondly, at the level of the decision.

The type of public support that is necessary at the level of the decision differs between the approaches. The local, market-based approach requires public support for the transition as a whole and requires public acceptance of the available set of alternative options for natural gas. Moreover, it requires that residents make active decisions. The objective for designing a communication-and-decision making process is that residents become willing and capable of decision-making in the heat transition. The regional, plan-based approach requires public support for the transition as a whole and requires public acceptance of the pre-selection of alternative options for natural gas. Moreover, it requires that residents have trust in the municipality and other related actors, that they make the right decisions. This means that the method for identifying resident perspectives on the phase-out of natural gas should provide insights in both levels of public acceptance of the transition. Moreover, it should provide insights in the importance residents attribute to freedom of choice with regard to alternatives for natural gas.

We have established that public acceptance is an important prerequisite for a successful heat transition. Transition management provides a suitable theoretic framework for investigating public acceptance as it fits with the legal distribution of mandate within the transition. Transition management tells us that developing a shared vision alongside building social networks and enabling learning processes are necessary for a successful transition and that collective learning and processes of shared decision-making can support public acceptance. Moreover, a recent research agenda on public acceptance for energy transitions suggests adding a social lens to thinking about public acceptance as this would provide better insights in what drives decision-making. The next step in the research is to develop a theoretic framework, which can function as the basis for designing a communication-and-decision making process that could support public acceptance of the heat transition. In 8.2 we will perform a structured literature review in which we discuss key-elements of residential decision-making in energy transitions and the potential influence of a process of participatory decision-making and collective learning and education. We will put an extra emphasis on subjectivity in decision-making.

9.2 LITERATURE REVIEW: DECISION-MAKING IN RESIDENTIAL ENERGY TRANSITIONS

The aim of the literature review is to investigate how individuals make decisions about residential energy investments and how participatory decision-making and collective learning and education can influence this decision-making process. The literature review focussed on the following four concepts, which were abstracted from the article of Rotmans et al. (2001) on transition management, the case description and the set of requirements in 8.1.4:

- Decision making on residential energy systems
- Participatory decision making

- Collective learning and education for public support
- Public support for energy policy
- Social learning systems

Appendix 7 describes the structured literature review. The review has resulted in the selection of three articles:

- *Models of decision making and residential energy use* (Wilson & Dowlatabadi, 2007)
- *How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands* (De Vente, Joris; Reed, Mark S.; Stringer, Lindsay C, et al., 2016)
- *Public values for energy futures: Framing, indeterminacy and policy making*, (Butler, C.; Demski, C.; Parkhill, K.; et al., 2015)

The structured literature review did not result in articles that cover the topics of social learning systems in relation to the energy sector. Therefore, the article of *Communities of Practice and Social learning systems* (Wenger, 2000), was added. This article is not specifically about public support or energy transitions. However, the article provided the closing link between the knowledge gap in article of Rotmans et al. (2001) with regard to designing a process of shared learning and decision-making, and the process design suggestions in the other articles. Moreover, to deepen our understanding of subjectivity in decision-making about residential energy systems, we have reviewed the literature from the PERSON research agenda on Social Sciences and Humanity research to facilitate a sustainable energy transition (2016).

In 8.2.1-8.2.3, the articles from the literature review are discussed in relation to residential decision-making in the context of the heat transition. This results in a theoretic framework describing residential decision-making in the context of the heat transition, and describing how participatory decision-making and collective learning and education can influence this decision-making process. In 8.2.1 we will focus on the decision making process, and the role of subjectivity. In 8.2.2. we will look into interventions for public acceptance in the heat transition and the position of participatory decision-making and collective learning and education. In 8.2.3, we will further deepen our understanding of participatory decision-making processes between residents and governmental organizations. In 8.2.4, we will evaluate the central position of values in decision-making processes and in 8.2.5 we will present a list of requirements for a process design based on this literature review. In 8.3, we will combine the information from the literature review in a theoretic framework.

9.2.1 DECISION MAKING ABOUT RESIDENTIAL ENERGY INNOVATIONS

The first step in building a theoretic framework for designing a communication-and-decision making process is to understand the residents' decision-making process on the investments in energy-related change within the household. Relevant models of individual decision making used in studies of technology diffusion in which social networks and technological attributes are key influences, are Rogers' (1983) Diffusion of Innovations model (DoI) and Sterns' model on proenvironmental behaviour (Wilson & Dowlatabadi, 2007).

In the DoI model *"The innovation-decision process is essentially an information-seeking and information-processing activity in which the individual is motivated to reduce uncertainty about the advantages and disadvantages of the innovation."* (Rogers, 1983, p. 14). When the individual is satisfied with the information, he or she makes a decision. For most individuals, the process of learning about innovations heavily depends on the subjective evaluation of an innovation that is conveyed to them by other individuals like themselves, who have already adopted the innovation (Rogers, 1983). Social feedback and observations of the technology are important for a positive attitude formation (Wilson & Dowlatabadi, 2007). In both models, values, believes and norms shape the perception or attitude of the decision-maker. Moreover, in both models behaviour is shaped by self-efficacy or capabilities. However, where the DoI model provides a structured description of the decision-making process, the proenvironmental behaviour model shows a more fuzzy or iterative process. Where the decision-structure of the DoI model allows for structured analysis of the decision-making process, the representation of the proenvironmental behaviour model may be closer to the reality of the heat transition, as the public debate on the transition is ongoing residents are currently continuously influenced through interactions with media and peers.

The diffusion of innovations through interactions with others is similar to a social learning process (Rogers, 1983). Rogers (1983) explains that both theories cover information exchange as the basis of convergence in cognitive and behavioural change. However, the DoI model focusses on the process of innovation adaptation and the adaptation speed. Where social learning is more about the information content of the exchanged knowledge. The information exchange between two or more individuals is key to the individuals' decision and its likelihood to act upon this. A process of collective learning influences: the prior conditions, the awareness and understanding of the problem and the attitude towards or perception of the problem. Besides this, subjective evaluations of peers who have already adopted the innovation are very important for the learning process of the individuals that are not early adaptors. This indicates that for the early and late majority of the residents, a process of collective learning can support the decision-making process in the heat transition.

Wilson and Dowlatabadi (2007) add a layer of cognitive dissonance and self-efficacy to the DoI model, to explain the link between cognition and action. Cognitive dissonance is the inconsistency between thoughts, beliefs, or attitudes, especially when it comes to behavioural decisions or attitude change. Individuals will act to change, or reject information in order to resolve or avoid cognitive dissonance (Wilson & Dowlatabadi, 2007). Self-efficacy is a person's belief about his or her ability or capacity to accomplish a task. Residents who doubt their own self-efficacy owing to a lack of resources, knowledge or access to the technology, may reject information to avoid creating cognitive dissonance between their knowledge and their lack of action (Wilson & Dowlatabadi, 2007). Key elements in residential decision-making in energy transitions are thus: cognitive dissonance, self-efficacy, which can both be influenced through collective (social) learning processes and the organization of resources.

INNOVATIVENESS

Rogers (1983) model for diffusion of innovation, which indicates that there are different types of adopter categories with regard to innovations ((1) innovators, (2) early adopters, (3) early majority, (4) late majority, and (5) laggards. These different types of adopters have different expected behaviour with regard to the transition. Moreover, they may respond differently to the relatively early stage the transition is currently in. Where the innovators and early adopters may be keen to take part in the transition, and have perhaps already taken some steps in the phase-out of natural gas, the early majority and the late majority needs more convincing. They are more likely to be willing to shift to district heating when this is becoming mainstream. Laggards are sceptic initially and are the last group to take part in the transition.

SUBJECTIVITY

It is important to emphasize that there are different types of decisions. The DoI model communicates structured decisions and the proenviroinmental model communicates a more unstructured decsion-making process. However, decisions range from deliberative, informed, and conscious choices to habitual, instinctive, and subconscious "non-decisions" (Wilson & Dowlatabadi, 2007). Moreover, individuals do not make consistent utility optimizing decisions. Time inconsistency, framing, reference dependence, bounded rationality and emotions are all phenomenon that can be related to decision-making about residential energy systems and should limit the expectations policy-makers have with regard to predictable decision-making of residents about residential energy systems.

When we look at the research agenda of PERSON, Hackermann et al (2014) state that it is necessary to adopt a social lens on energy transitions to establish the right societal responses to energy transitions. Hackermann et al (2014) distinguish six social frames: historical and contextual complexity, consequences, conditions and visions for change, interpretation and subjective decision-making, responsibilities, and governance and decision-making (Hackmann, Moser, & St. Clair, 2014). These social frames indicate that decisions about residential energy investments are influenced by amongst others: historical drivers of current behaviour and institutions, differences across contexts and identities, consequences of change for society, drivers of individual and collective change, normative agendas. Moreover, by subjectivity and the organization of decision-making processes. We will focus on these last two aspects as they are closely linked to the problem description and the analysis of the two approaches in the second part of the thesis.

In the lens of interpretation and subjective-decision-making implies that policy-makers should be sensitive to the values, beliefs, assumptions, interests, worldviews, hopes, needs and desires that underlie different responses to energy transitions. This fits with the findings of Perlaviciute and Steg (2014) that public support for energy alternatives in literature is adressed as a combination of characeristics of energy alternatives (collective and individual costs and benefits, and fairness related characteristics) and psychological factors (situation specific factors and values). Individuals will weigh preceived individual and collective costs and benefits, and preceived fairness to decide whether an energy alternative is acceptable. Acceptance of energy alternatives is related to the individuals understanding of factual characteristics, trust and values.

Hackermann et al. (2014) propose a stronger focus on the role of discourses and narratives in subjective sense making. These narratives contain deep-rooted assumptions and associated blind spots that underlie the choices and priorities of residents. It is therefore relevant to get a better understanding of these narratives. So that communication-and-decision making processes, can spiral around these assumptions and blind spots and fit with the resident's world-view, with the aim of achieving public acceptance. In addition, the lens of governance and decision-making implies that processes should be sensitive to decision-making under uncertainty, problem framing and negotiated knowledge. These concepts correlate strongly with the analysis of the two approaches for developing district heating in South Holland in the second section of this thesis. To deal with subjectivity in decision-making about the heat transition, it can be useful to develop a better understanding of the residents' perception of the problem, including problem framing and assumptions. In addition, to investigate how residents evaluate uncertainty of the heat-transition.

9.2.2 INTERVENTIONS FOR PUBLIC ACCEPTANCE

Wilson and Dowlatabati (2007) claim that action is the result of cognitive dissonance and self-efficacy. When an individual experiences inconsistencies or dissonance between its knowledge, attitudes, and actions, and finds itself in the position to resolve this dissonance, it will take action. Wilson and Dowlatabadi (2007) also discuss four types of interventions that could influence the individuals perception of changes in residential energy systems and potentially activate them to make a decision. These four categories are:

1) Supply chain interventions, which influence the individuals understanding of decision alternaives, their relative attractiveness and the constraints on choices.
2) Moralsuasion/education interventions, which influence the individuals beliefs/attitudes or activate norms.
3) Policy/regulation interventions, which influence external conditions, incentive structure and decision-drivers.
4) Community management interventions, which change social norms.

These interventions show a parallel to science communication, which is aimed at realizing public support for science and technology. Making this link to science communication models and trends explicit helps us in understanding how these interventions could shape public support for the heat transition.

The first "supply-chain" category can be linked to the knowledge-deficit model, a model that originates in science-communication in the 1960's, which implies that better understanding of science and technology will result in better acceptance. Realizing 'scientific literacy' requires primarily top-down, one-way communication processes. However, there is no evidence that 'scientific literacy' results in better acceptance of science and technology (Wehrmann & Dijkstra, 2017). Moreover, communicating about science and technology takes place in a social context and their social identity will influence their perception, arguably more than factual knowledge. The second category of moralsuasion/education, can be linked to the trend of "understanding science" in science communication, which was a reaction to the knowledge-deficit model. This trend assumes that understanding science, which can be measured in terms of attitudes and perceptions, plays an important role in making informed choices. This type of communication is aimed at convincing the public. However, again research has shown that this does not always result in people having a more positive attitude towards science and technology (Wehrmann & Dijkstra, 2017). Some people become more critical and their trust in science and technology can decrease. Moreover, third "policy/regulation interventions" category influences external conditions, incentive structure and decision-drivers. This type of intervention assumes non-subjective decision-making, where individuals have the right information and decisions are influenced by relative advantages. However, in section 9.1.1 we have discussed that this is not the only type of decision-making and that a process-design should be sensitive to subjectivity. Interventions of these first three types therefore may not result in public acceptance of the heat transition.

The third trend in science communication uses the notion that science is at work in a society in which trust in science is itself a regular topic of discussion. It assumes that trust in science and technology is built through dialogue with multiple actors. In addition, that it is necessary that more attention be given to uncertain outcomes. Public acceptance of science and technology is achieved through an open dialogue. This links to the fourth type of interventions, interventions on community management, where the response to science and technology is a topic of discussion. However, these open dialogues are time-consuming, they are often organized top-down and the results are often disappointing (Wehrmann & Dijkstra, 2017). According to critics, these disappointing results are attributable to top-down organization and pre-determined outcomes (Wehrmann & Dijkstra, 2017). This parallel to public acceptance of science and technology shows that it is necessary to maintain a balance between popularization and participation on the topic of science and technology, to achieve public acceptance (Wehrmann & Dijkstra, 2017). Interventions purely focussed on supply-chain knowlegde, moralsuasion/education and policy./regulation, will not suffice. From this parrallel to science-communication we learn that a method to realize public acceptance for the heat transition should facilitate both factual knowledge exchange and interaction on social norms, and activate resources.

COMMUNITIES OF PRACTICE

The next question is how collective learning and shared decision-making as proposed by Rotmans et al. (2001) fit in this framework. Processes of collective learning occur as we interact with the world around us. "*Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly."*(Wenger, 2011, p. 1) *or to deepen their knowledge on a specific topic* (Bertone et al., 2013, p. 1). Examples of Communities of practice (CoP) are a think tank or a professional association (for example Logeion). A CoP can be described in terms of events, leadership, connectivity, membership, projects and artefacts. Communities of practice naturally emerge; however, communities of practice can also be used instrumentally. *"From an instrumental perspective, a community of practice can be viewed as a learning partnership."* (Wenger, 2010, p. 12). Learning partnerships can be initiated as a means to facilitate a process of collective learning. As described in 8.1, collective learning can lead to convergence in cognitive and behavioural change, which can play an important role in decision-making about residential energy investments. A CoP can influence the individual decision-making process at the stages of knowledge and persuasion.

Municipalities can initiate communities of practice (in existing social systems) to seek for agreement and alignment across the social system about the transition pathway for the local phase-out of natural gas. Wenger (2010) calls this *Stewarding governance*. The municipality as a facilitator mobilizes critical resources (knowledge, time, funds, political support and technology) through organizing processes, which foster human interaction (Bertone et al., 2013). Moreover, through interaction, municipalities could get a better understanding of the important values, believes and (local) contexts of residents with regard to the heat transition. In addition, develop an understanding of the subjectivities of residents that shape their decision-making.

The design of communities of practice is debated. "*The concept of community of practice started out as an analytical concept, giving a name to a phenomenon that already existed*"(Wenger, 2010, p. 10). Nowadays communities of practice are frequently designed intentionally to facilitate learning. If it becomes a "design intention" or a "prescribed process" then it loses the very insights that made it useful (Vann and Bowker, 2001). "*Many "designed" communities of practice fail or die early…. And it is indeed difficult to find the right balance between enough formality to give them legitimacy in the organization and enough informality to let them be peer-oriented, self-governed learning partnerships.'*(Wenger, 2010, p. 11) It is therefore necessary to keep in mind that key-concepts of communities of practice are self-governance, voluntary participation, personal meaning, identity, boundary crossing and peer-to-peer connections. The design of the CoP should therefore fit with the participants needs with regard to the organization and should be flexible enough to adapt to potentially changing needs. Moreover, a prerequisite of such a learning partnerships is that there is mutual recognition among the participants as potential learning partners. Learning processes in communities of practice cannot be enforced. It is learning that drives governance, and not the other way around (Wenger, 2010). Bertone et al. (2013) explain that from the instrumental perspective, the participation in a community of practice is driven by both individual and collective goals. This means that the objectives and activities of the community of practice need to be in line with the residents' perception of the problem and the anticipated outcomes. Moreover, the community dimension of a community of practice needs to be designed (power structure, regulatory mechanism, trust and ownership) in order to create a learning environment.

In conclusion, municipalities can stimulate the realization of a community of practice as a means of agreement and alignment among residents about the local transition pathway for the phase-out of natural gas. When the municipality positions itself as a learning partner, and listens well to the (subjective) understanding of residents of the transition, the CoP can be used to facilitate factual knowledge exchange, activate social norms and mobilize resources that fits with the residents' world-view and needs in the transition. However, such a community can only be successful the environment that is created that fit with the participants desires towards the process-design and outcomes: participation level, content: personal meaning, identity, boundary crossing, organizational structure and, individual and collective goals.

9.2.3 PARTICIPATORY DECISION MAKING PROCESS DESIGN

Communities of practice are places for social learning. However, as Rotmans et al. (2001) describe, besides learning, shared decision making processes may also contribute to public acceptance. De Vente et al (2016) researched the effect of the context and design of a participatory decision making process on the outcome in the context of sustainable land management in Spain and Portugal. The cultural context of the research is very different from the context in this research, and therefore conclusions on the effect of the process design parameters are excluded. However, the article of De Vente et al. (2016) provides some practical insight in the process design variables, prospective outcomes and participation levels, for participatory decision-making process where both residents and local governments are involved.

De Vente et al (2016) describe very detailed process design parameters. At a high level, these process design variables for participatory decision-making processes cover: the selection of participants (free, organized) and the legitimacy of the representation, the types of stakeholders that are included in the process (state, non-state, residents etc.), the roles the competent authority has (initiator, participant, mediator, facilitator etc.) and the organization of interactions, both in practical terms and in terms of rules of the game. De Vente et al. (2016) describe five prospective outcomes of participatory decision-making processes: enhanced social networks, learning and knowledge exchange, better problem identification, consensus and acceptance and motivated stakeholders.

De Vente et al. (2016) describes two participation levels of participatory decision-making processes: passive participation or active participation. Passive participation means that the resident only desires to receive information. There are different levels of active participation: participation by consultation (questionnaires, interviews, workshop), functional participation (focus group, meetings, communication by regional government, training sessions, workshops), interactive participation (stakeholder meetings, questionnaires, workshops, scenario building, field demonstration, newsletters) and self-mobilization (field survey, workshops, public meetings) (De Vente et al., 2016; Pretty, 1995).

These process design variables and prospective outcomes for participatory decision-making process actually to a large extend overlap with the design of a community of practice. This makes sense as (social-) learning is an important aspect of the decision-making process. However, this article also shows that for participatory decision-making processes between residents and governments, resident participation levels can differ from the interactive participation or self-mobilization a CoP requires. It is not clear from the article if interactive participation or self-mobilization leads to better results with regard to the prospective outcomes than participation levels that require less time and effort from residents, such as participation by consultation or functional participation.

In conclusion, a CoP can be suitable to facilitate a process of shared decision making, as it facilitates (social-) learning which is an important aspect of the decision-making process. However, evaluation of shared decision-making processes on sustainable land-use in Portugal and Spain suggests that the interactive participation or self-mobilization a CoP requires may not be necessary for a successful shared decision-making processes. In combination with the notion of voluntary participation, it is therefore necessary to carefully investigate what level of participants actually find useful.

9.2.4 PUBLIC VALUES IN ENERGY SYSTEM CHANGE

In 8.2.3 we have discussed the design of a CoP in relation to the organization of collective learning and shared decision-making processes. However, we have not yet discussed the content of the CoP. From 8.1.1 and 8.1.2, we have learned that the content of the learning-activities in a CoP should fit with what the participant finds relevant or interesting. We have seen that values shape attitudes and behaviour.

Butler et al. (2015) researched the public acceptability of policy in energy transitions in the UK because public acceptability represents an indeterminate form of uncertainty in the transition of energy systems that presents particular challenges for policy making (Butler, Demski, Parkhill, Pidgeon, & Spence, 2015). The article of Butler et al. (2015) indicates that public acceptance of energy transition policy is influenced by the extent to which the policy adheres to the individuals value system with regard to energy transitions. The value system developed by Butler et al. (2015) gives insight into how the residents view energy system change should be in terms of both process and outcome. Butler et al. (2015) identified the following set of values:

- Efficient and not wasteful – efficient use of energy and minimizing waste
- Protection of environment and nature – environmentally conscious
- Security and stability – safe, reliable and accessible
- Autonomy and power – both at national and personal levels
- Social justice and fairness – open, transparent fair, and attentive to the effect of peoples' lives
- Improvement and quality – improvements of quality of life

Butler et al. (2015) found that in UK policy documents the problem framings were often much narrower than the public problem framings. They propose to create a coalition between governments and residents, in which governments can learn about resident perspectives on energy policy, to broadening the narrow focus of problem framings. "*Building from a renewed basis in terms of problem framing that accounts for more diverse public values and interpretations, is likely to offer a far greater set of opportunities for convergence on possible solutions.*"(Butler et al., 2015, p. 671).

This article indicates that to develop effective energy policy, it is necessary that the policy relate to residents' value systems. As such, it relevant for governments to learn about residents' value-systems with regard to energy policy.

9.2.5 REQUIREMENTS FOR A PROCESS DESIGN

In section 9.1.1 -9.1.3 we have further deepened the understanding of the dynamics related to public acceptance in energy transitions. This has led to a set of recommendations for a design of a communication-and-decision making process for realising public acceptance for this heat transition:

1. Facillitate both factual knowledge exchange and interactions with peers shat will shape social norms.
2. Make sure the process is based on trust amongst the participants.
3. Overcome practical shortcomings individuals may experience.
4. Be sensitive to residents' attitudes towards decision-making under uncertainty.
5. Be sensitive to desired levels of participation of residents.
6. Be sensitive to problem framing and negotiated knowledge: understand that diverse and deep-rooted assumptions and associated blind spots can steer the choices and priorities of residents.
7. Be sensitive to residents' value system with regard to energy transitions, and adapt the learning process to fit these values.
8. Be sensitive to the difference between acceptance of the transition as a whole, and acceptance of the resulting position of the individual in the transition.

Moreover, the aim of a communication-and decision-making process is to develop a shared vision alongside building social networks and enabling learning processes. It is necessary that the organizers accept that this process may influence the outcome of the transition and embrace the opportunity the process provides to learn from residents.

9.3 THEORETIC FRAMEWORK

The four theories described in 8.1.1-8.1.4 combined result in a theoretic framework for realizing public support in the heat transition at a municipal level. This theoretic framework is shown in figure 49.

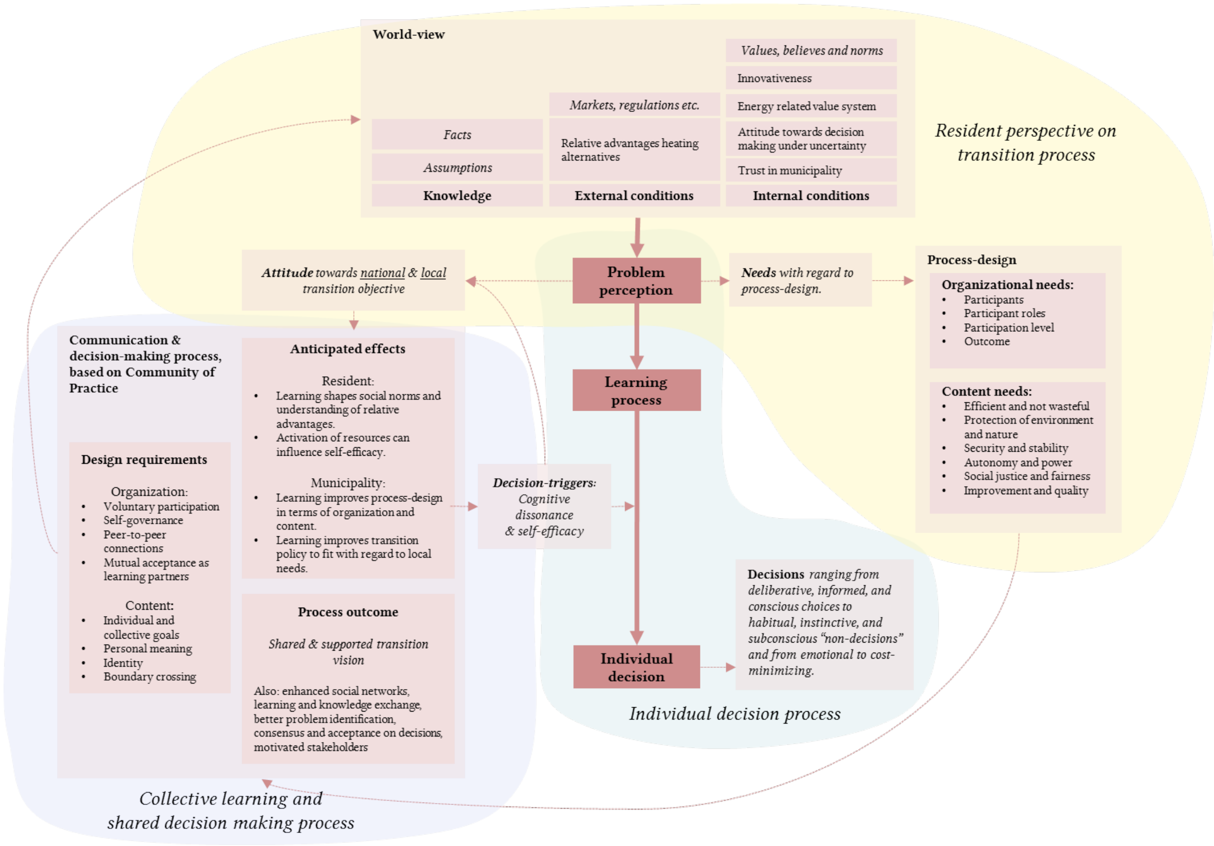


Figure 49 Theoretic framework: resident perspective on communication and decision-making process design in the heat transition

The world-view describes what residents know about the transition, based on facts and on assumptions, and how they evaluate this knowledge given the internal and external conditions. Internal conditions describe the residents values, believes and norms. In relation to the process-design for the heat-transition, important aspects of these internal conditions are the values residents find important with regard to energy-supply, the residents' attitude towards decision-making under uncertainty, the residents innovativeness and the residents trust in the municipality. Important aspects of the external conditions are the factors that influence the relative (financial, aesthetic etc.) advantages of the different alternatives for natural-gas heating.

The world-view results in the residents' problem perception. The problem perception describes how the resident perceives the transition: the attitude towards national and local transition objectives, and the relative importance of different aspects of the transition. The problem perception indicates what the resident needs with regard to the process design, in terms of organization and content. This knowledge about the needs with regard to the process design, and the attitude towards the transition, can be used to design a communication-and-decision making process. The design requirements show that it is necessary to carefully consider the process-design needs and attitude of the resident with regard to the design of the communication-and-decision-making process.

The municipality can initiate an interactive collective learning-and shared decision-making process to 1) shape or activate social norms of residents and 2) enhance the understanding of relative advantages of alternatives for natural gas of residents. However, to be effective it is also necessary to facilitate the activation of resources: financial resources/advantages, access to specialists, and access to installers etc., to reduce the practical issues related to decision-making. This process of social learning and resource activation can activate the decision-triggers of cognitive dissonance and self-efficacy.

Through this process, the municipality can learn from residents with regard to 1) the desired organization of the transition process, 2) the values residents find important in transition policy and 3) local contexts and transition narratives that shape decision-making in the transition. This process can result in a shared and supported vision on the transition, energy policy that fits better with local needs and residents that are both willing and capable of decision-making. Moreover, it can result in enhanced social networks, learning and knowledge exchange, better problem identification, consensus and acceptance on decisions and motivated stakeholders. As a result of this collective learning and shared-decision making process, residents can make individual decisions about their actions in the transition, which can range from deliberative, informed, and conscious choices to habitual, instinctive, and subconscious "non-decisions" and from cost-minimizing decisions to emotional decisions.

The communication-and-decision-making process itself will shape the residents world-view. As such, the process itself will have an effect of the residents' needs with regard to the process. It is therefore important that the process-design is not rigid, but can adapt to the changing needs of the participants.

9.4 CONCLUSION

In this chapter, we have answered the sub-question: *How can the design of decision-and-communication processes contribute to the public acceptance of the heat transition?*. We have seen that the mandate in the transition currently lies with the individual homeowner and majority-groups of tenants. This is a critical factor for the success of both approaches for the realization of district heating infrastructure in South Holland. Literature indicates that for residents to take-action in residential energy transitions, like the phase-out of natural gas, self-efficacy and cognitive dissonance are important factors. In addition, literature indicates that a process of collective learning- and decision-making can influence these two factors as it can provide access to knowledge and resources and, ignite cognitive dissonance, because of interactions with peers and professionals.

Effective processes collective learning- and decision-making fit with the participants needs with regard to the process. To design an effective communication-and-decision-making process, it is therefore necessary to develop an understanding of the perspective of residents on these process-design inputs. From the literature review we have derived the following set of needs with regard to the process design:

- Problem perception
- Organizational needs
    - Desired participants
    - Desired participant roles
    - Desired participation level
    - Desired outcome
- Content needs
    - Efficient and not wasteful
    - Protection of environment and nature
    - Security and stability
    - Autonomy and power
    - Social justice and fairness
    - Improvement and quality

In the next chapter we will show how Q-methodological research can provide insights in the perspective of residents on these process-design inputs.

10.

IDENTIFYING RESIDENT PERSPECTIVES ON THE PROCESS OF THE PHASE-OUT OF NATURAL GAS

How can municipalities identify the perspectives of residents on the process of the phase-out of natural gas?

In chapter 9 we have developed a theoretic framework for designing communication-and-decision making processes in the phase-out of natural gas. The theoretic framework indicates that a process of collective learning and decision-making can contribute to realizing public acceptance for the transition to gas-free district and potentially the implementation of district heating systems. The framework indicates that it is necessary that the process-design fit with residents' problem perception, and process and content related needs. Currently, it is unclear what these problem perceptions, and process and content related needs of residents are. Moreover, it is unclear how municipalities can investigate these perspectives. In this chapter, we apply Q-methodology as a method to identify these resident perspectives on the process of the phase-out of natural gas. We show how Q-methodology is applied in the context of this research, and which choices are made. First, we provide an overview of the research steps and then the chapter continues with the discussion of the discourse analysis (10.1), which is followed by the selection of statements (10.2) and the selection of participants (10.3) and the data collection (10.4). Then the processing of the results and the factor analysis in 10.5, and factor interpretation and the creation of narratives in 10.6. Section 10.7, contains the conclusion on the main findings from this research step. In chapter 11 the content of the perspectives will be discussed.

To determine how municipalities can identify perspectives of residents on the municipal governance of the implementation of district heating networks in their own neighbourhood, we have evaluated several research methods for subjectivity this is discussed in section 2.2.3. This resulted in the selection of Q-methodology as the research method. Q-methodology ordinarily adopts a multiple-participant format and is most often deployed in order to explore and make sense of highly complex and socially contested concepts and subject matters from the point of view of a group of participants involved (Watts & Stenner, 2005). In Q-methodological research, participants are asked to structure a set of statements following a fixed procedure, while commenting on their ways of thought. This ordering of statements plus the adjoining comments are evaluated to identify overlap in the subjective though processes of the respondents and as such, identify perspectives on the topic at hand.

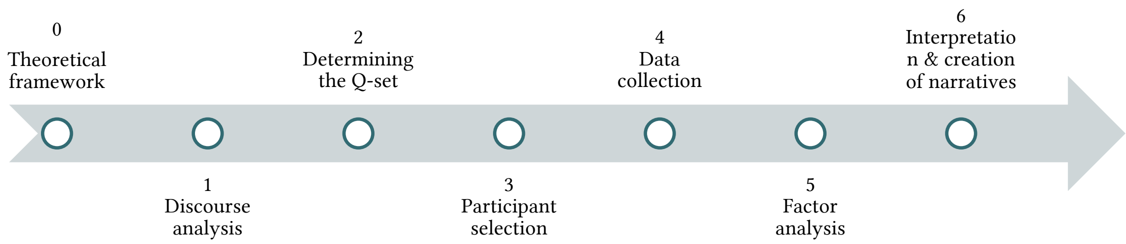


Figure 50 Process steps Q-methodology

The Q-methodology will be applied according to the guidelines of Watts and Stenner (2005). Q-methodological research consists of six steps. Figure 50 shows the steps taken in the process of Q-methodological research. Step 0 is added to the process prescribed by Watts and Stenner (2005). This step describes the development of theoretic framework which can be used to evaluate the completeness of the discourse analysis and support the interpretation of the identified perspectives. This is the theoretic framework developed in chapter 8. In section 10.1-10.6 each of these individual steps is discussed.

10.1 DISCOURSE ANALYSIS

The first step in Q-methodological research is to perform a discourse analysis and develop an initial set of statements. A discourse analysis is a review of written or spoken text and images, which tell something about the different perspectives individuals may have with regard to topic of research. It is also possible to perform interviews with the respondents, to complement the existing discourse. For this research, we have chosen to perform a review of the existing grey-literature on the phase out of natural gas.

Most reports on the phase-out of natural gas focus on the technical, economic and legal challenges of the transition (CE Delft, 2015; Ecorys, Innoforte, Energy Finance Institute, & if, 2016; Planbureau voor de Leefomgeving, 2017a, 2017b; Warmte Koude Zuid-Holland, Alliander, Berenschot, Agro Energy, E.on, Prominent, Provincie Zuid-Holland, LTO Glaskracht, 2015; Wijngaart, 2012). There is however less information available about the resident perspectives on the transition. In consultation with Programmabureau Warmte Koude Zuid Holland and HIER Klimaatbureau, two organizations who are currently actively engaged in resident-communication on the phase-out of natural gas, the following six data-sources were selected:

1. 12x Visies op wonen zonder aardgas (2017, HIER Klimaatbureau)
   In this report 12 professionals in the energy sector, with varying backgrounds react on an opinion article written by Hier Klimaatbureau, on the phase-out of natural gas. Most professionals also respond on the role of residents and the position of a participatory process for decision-making.
2. Van de Kook – Verhalen voor een gas(t) vrije wijk - Sociale innovatie voor een sociaal robuuste transitie naar wonen zonder aardgas. Notten, 2016)
   Kirsten Notten collected daily experiences of normal residents with regard to energy. She used this as a starting point for the discussion about the realization of natural gas free districts. This resulted in process related recommendations for municipalities in the phase-out of natural gas.
3. # vangaslos, de beleving van de burger centraal tijden de aardgastransitie
   This is a communication approach for municipalities in the phase-out of natural gas. It explains the transition to communication employees of municipalities and provides guiding principles for the phase-out of natural gas, from the perspective of a resident.
4. Bewonerservaringen aardgasloos wonen (HIER Verwarmt, 2018)
   This is a web-page containing stories about residents that have built or remodelled their house to become independent of natural gas. Residents talk about their motives and struggles in this transition.
5. Tips & Tricks bewonerscommunicatie (HIER Klimaatbureau, 2017b)
   This is a presentation containing experience-based communication-advice for municipalities about the phase-out of natural gas. The presentation contains some striking examples on how residents have reacted to messages about the transition.

6. Qualitative results research public perception on gas-free districts (2016 & 2017), conducted by HIER Klimaatbureau.
HIER Klimaatbureau performs annual research into the public perception on gas-free districts. While the questions are multiple-choice, the respondents have the option to react to each of the questions. HIER Klimaatbureau provided these written reactions. This data shows how people react to messages about the transition in an anonymous and digital setting.

Moreover, we visited several information meetings for both professionals and residents on the topic of the phase-out of natural gas. Relevant meetings were:

- 28th of February 2017 – Platform gas uit de gebouwde omgeving – Professionals
    - Pijnacker-Nootdorp: experience with phasing-out natural gas in the built environment
    - Rotterdam: Social marketing for the phase-out of natural gas
- 10-12 May 2017 – VanGasLos Festival – Professionals, Municipalities and residents
    - Information market on the phase-out of natural gas
- 25th of September 2017 – Partner en ledendag Klimaatverbond en HIER Klimaatbureau
- 20th of February 2018 – Kick-off DEZO project 'Segwhaert maakt Vaart'

This has resulted in a collection of 195 statements that say something about the process of the phase-out of natural gas. The next step is to organize these statements and to develop a balanced set of statements that can be used in the experiment.

10.2 SELECTION OF STATEMENTS

The second step in Q-methodological research is to develop a set of statements for the experiment. Typically, a Q-set has somewhere between 40 and 80 statements (Watts & Stenner, 2005). Smaller sets of statements can result in inadequate coverage of the topic, and larger sets of statements can become impractical. We will develop a structured set of statements. This set of statements is developed based on the results of the discourse analysis, and the theoretical framework developed in chapter 8. The set of statements should contain statements relating to the following categories:

- Problem perception
- Organizational needs
- Content needs

Alternatively, an unstructured q-set could be developed. An unstructured q-set assumes that you have no preconceptions about what factors are important for the perspectives. However, since we have derived from the framework that it is necessary to gain insights in the resident perspectives with regard to the following categories: the residents' attitude towards the transition, organizational needs and content needs, we have chosen to develop a structured q-set.

The Q-set is a dynamic medium through which subjectivity can be actively expressed. Therefore, A q-set should be balanced and representative (Watts & Stenner, 2005). This means that the q-set should capture the full range of possible opinions and perspectives in relation to the research question. In addition, it means that the representation of the aforementioned themes in the set of statements should be sensible. The initial 195 statements gathered as described in 9.1 were clustered based on their content and then re-organized in distinctive themes relating to the theoretic framework as described in chapter 8. Overlapping statements were removed and some statements were clarified to be comprehensible without the context of the discourse they originated from. This resulted in a list of 58 statements. The list of statements can be found in appendix 9. Table 44 shows the framework used for the development of the structured q-set. Table 37 also shows the distribution of the statements over the framework.

Table 43 Framework for structured q-set

Problem perception	#	Organizational needs	#	Content needs	#
Knowledge about the transition	2	Desired participants: municipality, residents, local energy initiatives and commercial parties.	5	Efficient and not wasteful	
Innovativeness of the resident: desires with regard to the timing and phasing of the transition	6	Desired participant roles: leadership, authority and representation.	6	Protection of environment and nature	1
Attitude towards the national and local transition objective	6	Desired participation level: passive participation, participation by consultation, functional participation, interactive participation and self-mobilization.	4	Security and stability	4
Current level of self-efficacy	3			Autonomy and power	2
Attitude towards decision-making under uncertainty	1	Desired outcome: enhanced social networks, learning and knowledge exchange, better problem identification, consensus and acceptance and motivated stakeholders.	8	Social justice and fairness	3
Trust in municipality	1			Improvement and quality	6

To check if the resulting set of statements is sufficiently complete, balanced and comprehensible, the set of statements was checked by three individuals:

- one man in his late 30s, with an MBO education, who has no further knowledge about the transition
- one man in his early 40s, with a university degree, who is well informed on the transition
- one woman in her early 40s, with a university degree, who is an expert on the transition

Moreover, we have performed a test-run of the complete experiment, with a man in his late 20's, with a university degree who is well informed on the transition. Based on these four checks we have established that the set of statements is sufficiently complete, balanced and comprehensible to be used for expressing an individual perspective on the phase-out of natural gas.

10.3 PARTICIPANT SELECTION

The third Q-methodological research is the selection of participants. The suggested size of a participant group lies between 40-60 individuals. However, studies with fewer participants can also be highly effective and participants can be selected strategically if it seems likely they will express a particularly interesting viewpoint (Watts & Stenner, 2005). Moreover, there is even a form of single-participant research-design where a single respondent is asked to perform the structuring process a number of times under different conditions(Watts & Stenner, 2005).

For this research, we have selected a multiple-participant design. The participants are selected strategically, to reduce the number of necessary interviews. The selection of participants is based on their residential status (homeowner or tenant) their income, their age and their education level as these four characteristics are expected to influence the participants' worldview. In addition, we have chosen to selected participants within a single district. The process of the phase-out of natural gas is often referred to at a district level. The geographical borders of a district form the basis for formulating transition plans. It is therefore interesting to see if Q-methodological research can provide insights in the different perspectives on the phase-out of natural gas within such geographical bounds.

10.3.1 CASE SELECTION

We are evaluating if Q-methodology is a research method that can provide useful insights in resident' perspectives on the process of the phase-out of natural gas in South Holland. We are interested in researching if this method could support the development of public acceptance for the heat transition in this province in general. Therefore, for the selection of a district, we have adopted the following criteria:

- The district should be an average district within South Holland, with regard to relevant and available socio-economic characteristics (property value and home ownership).
- The district should contain neighbourhoods that are suitable for district heating and that are common within the Netherlands: Bloemkoolwijk with a high density of households (13%), neighbourhood within the first ring around the old inner city (12%), or a recently new-build neighbourhood (12%) (CE Delft, 2015). These districts typically have a relatively high population density, a relatively high degree over urbanization and were built after the second world war.

- The district should be located within the defined area of the scope of the research in the second section of this thesis. It should be a district in which both the approach of the PZH and the approach of the PBL could be selected.

Based on these three criteria, the district Seghwaert in Zoetermeer was selected. Seghwaert consists of two neighbourhoods: Seghwaert-Zuid-West and Seghwaert-Noord-Oost. These two neighborhoods have very similar characteristics.

1) Seghwaert strongly resembles an average Dutch district in terms of socio-economic characteristics (CBS, 2017). The analysis of the CBS shows that (CBS, 2017): in 2015 the average annual income of a household in Seghwaert was €35.600. This is 1100 euro higher than the national average. Approximately 55% of the houses was individually owned, and 45% of the houses were rental accommodations. This is the same as the Dutch average.
2) Seghwaert is a Bloemkoolwijk build in the late 1970's early 1980's. Moreover, Seghwaert has a relatively high density of households and a high degree of urbanization. As such, the district could be suitable for a district heating network.
3) Seghwaert lies in Zoetermeer. Zoetermeer is one of the municipalities that could be connected to the main heat infrastructure planned by the PZH.

In Zoetermeer there is a slightly higher percentage of rental properties owned by social housing agencies than the average in the Netherlands. It is unclear if this is also the case in Seghwaert specifically. However, the research is not focussed on identifying the exact share of residents that support this perspective. Therefore, this should not be an issue.

When we compare the district Seghwaert and the neighbourhoods Seghwaert-Zuid-West and Seghwaert-Noord-Oost, to all other districts in The Netherland, with respect to the population density, the average value of the property, the degree of urbanization and the age of the buildings, there are 39 similar districts and 139 similar neighbourhoods. 42 Of these neighbourhoods are located in the area of the scope of the research in the second section of this thesis. Therefore, we conclude that Seghwaert is a good example of an average district in South Holland. In addition, if Q-methodology provides useful insights in the resident perspectives on the process of natural gas in this district, this could indicate that this method could provide relevant insights in the many similar districts and neighbourhoods in South Holland.

10.3.2 RESPONDENT SELECTION

All selected respondents are residents of Seghwaert. The participants are selected strategically based on their socio-economic status and their knowledge about and historic actions towards sustainable energy consumption. This is done to reduce the number of necessary interviews. Ideally, we want to select participants that differ strongly with regard to these characteristics. The respondents were found through:

- An evening on sustainable home-improvements in the community centre (4)
- The local primary school (2)
- Through other respondents (snowball, 3 direct connections)

All participants have received an invitation letter. This invitation letter can be found in appendix 8.

Because of limited time and limited available respondents, there is some overlap in the socio-economic characteristics. In addition, there were respondents with an education level of VMBO/MAVO or lower, or with an income level below modal. Table 45 shows the combination of the socio-economic characteristics and the respondent numbers. Respondent 6 and 9 and respondent 7 and 12 have the same socio-economic characteristics, however respondent 6 and 7 were not aware of the transition prior to engaging in the research, where respondent 9 and 12 were. All other respondents are unique with regard to their socio-economic characteristics.

Table 44 Overview socio-economic characteristics respondents

#	Age	Gender	Home ownership	Education level	Income level	Awareness transition	Sustainable home improvements
1	35	Male	Home owner	WO-master/Higher	Modal income	Yes	Yes
2	69	Female	Home owner – in AO	WO-master/Higher	Above modal income	Yes	Yes
3	64	Male	Home owner	HAVO/VWO/MBO	Modal income	Yes	Yes
4	56	Female	Home owner	WO-master/Higher	Above modal income	Yes	Yes
5	52	Female	Tennant	HBO/WO-bachelor	Above modal income	Yes	No
6	56	Male	Home owner	HAVO/VWO/MBO	Above modal income	No	No
7	56	Male	Home owner	HBO/WO-bachelor	Above modal income	No	No
8	70	Male	Home owner	WO-master/Higher	Modal income	Yes	Yes
9	52	Male	Home owner	HAVO/VWO/MBO	Above modal income	Yes	No
10	25	Female	Tennant	HBO/WO-bachelor	Modal income	Yes	Yes
11	58	Male	Tennant	HBO/WO-bachelor	Above modal income	Yes	No
12	56	Male	Home owner	HBO/WO-bachelor	Above modal income	Yes	No
13	25	Female	Home owner – in AO	HBO/WO-bachelor	Modal income	No	No
14	76	Male	Home owner	WO-master/Higher	Above modal income	Yes	Yes

10.4 DATA COLLECTION

The fourth step in Q-methodological research is the collection of data. This step consists of individual interviews with each of the participants. Figure 51 shows the steps within these interviews.

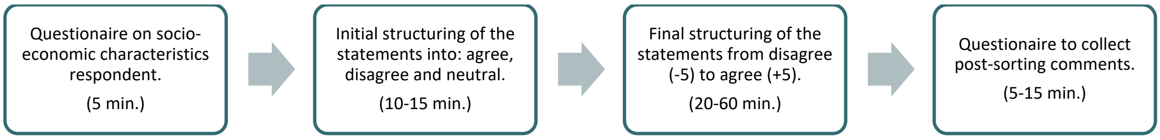


Figure 51 Process of data collection in interviews

During these interviews, the participants are asked to structure the set of 58 statements. The first step in te interview is a general questionnaire on the socio-economic characteristics of the respondent. The second step the interview is the quick-scan in which the participants decide whether they agree or disagree with a statement. Alternatively, they can be neutral towards the statement. In the third step, the participants are asked to plot the statement-cards on a normal-distribution. The extremes of the distribution have a factor score of +5 for "most agree" and -5 for "most disagree". Zero indicates that the respondent is indifferent. During this process, the respondents were asked to express their arguments for structuring the statements in their own particular way. These statements support the data-interpretation. The final step is to collect post-sorting comments. These post-sort comments also help the researcher later to interpret the sorting configuration by investigating: 1) the participants' interpretation of high and low ranked items, and the implications of this on the context of their overall viewpoint; 2) shortcomings of the q-set and; 3) other items the participant wants to comment on (Watts & Stenner, 2005). The questionnaires and the form used for structuring the statements is found in appendix 9.

INTERVIEWS

The interviews were conducted between the 2nd of march and the 16th of march 2018. The interviews were all individual interviews that took place at a location of choice of the respondent. This was either at home or at work. Each interview lasted between 45 minutes and 2 hours. No prior in-depth information about gas-free districts was shared with the respondents. This was done to refrain from influencing the respondents a-priori. Moreover, individual action towards gathering information and awareness of the transition are expected to be a part of the respondent's attitude towards the transition.

To support the quantitative interpretation of the q-sorts, all interviews were recorded and during the interviews, comments of the respondents about the statement-cards were written down. These recordings are not transcribed, but are accessible for reviewing and are available upon request. Moreover, an overview of the comments of respondents on the statements is available upon request. The post-sorting comments indicate that the respondents were satisfied with the resulting ordering of the statements. They experienced that the set of statements was sufficiently complete and balanced to be used to adequately represent their opinion on the process of the phase-out of natural gas. Moreover, all respondents have indicated that they found the process of structuring the statements interesting. In addition, all respondents have replied that this interview has activated them to further read-up on the transition or that they feel that they are now better prepared when they will receive a message that the transition is current in their district or neighbourhood, as they have already given it some thought. The participation in the Q-study is a first step in the process of communication-and-decision making.

Some respondent have indicated that they had difficulties interpreting some statements. In particular, statement 16 and 19 were difficult to interpret. Moreover, some respondents have indicates that some statements actually consisted of two statements. In particular, statement 36 was frequently mentioned. These comments were all written down and will be carefully considered when interpreting the data.

10.5 FACTOR ANALYSIS

The fifth step in Q-methodological research is the factor analysis. The Q-sorts are analysed using the software package PQMethods, as recommended by Watts and Stenner (2012) and KenQ, which is an online tool, which facilitates easier exploration of the Q-sorts than PQMethods does. The factor analysis is the process of identifying different distinguishing perspectives on the topic. There are two methods for factor extraction; the first method is the CFA (centroid factor analysis) and the second is PCA (principal component analysis). Within the research field of Q-methodology, there is an ongoing debate on the preferential status of either of the two approaches (Watts & Stenner, 2005).

- PCA is a data reduction method. It results in a mathematically best representation of the shared perspective among the respondents, which explains the most variance amongst the q-sets of the respondents. This perspective should be accepted by the researcher as the best representation of the subjectivity amongst the participants (Watts & Stenner, 2012).
- CFA is also a data reduction method. However, CFA estimates latent variables, which influence responses on the observed variables.

Watts and Stenner (2012), advocate the use of CFA as this method allows for better data exploration, and does not force the researcher to accept a single best solution. There is no theoretical basis to use PCA in the context of the research; therefore as recommended by Watts and Stenner (2012), CFA is used. In the selection of the number of factors, three criteria suggested by Watts and Stenner (2012) were used:

1) Maximize the number of q-sorts that have a unique and significant factor loading on one of the factors.
2) Maximize the overall explained variance.
3) Only include factors with at least two q-sorts that have a unique and significant factor loading.
4) Make sure the factors are internally consistent; the statements make sense in relation to each other.

Based on these four criteria, four factors were extracted. These four factors were rotated using Varimax rotation to ensure a better fit with the data. Alternatively, the factors could be rotated manually. This manual rotation leaves more room for the researcher to interpret the data based on the quantitative insights gathered. However, this can be a timely process and requires experience. Finally, three out of these four factors were accepted. Factor 3 was excluded from the analysis as, after rotation, none of the q-sorts loaded significantly on the factor.

The eigenvalues of the factors and the factor-loadings indicate that no saturation of the data has taken place. This means that there is insufficient data to draw conclusions about the finite number of diverse perspectives that exist on the phase-out of natural gas within the respondent pool. This indicates that additional interviews can result in a different number of perspectives. Moreover, the composition of the statements within each perspectives could change as a result of adding data. Because of the limited time for this research, and because the perspectives seem internally consistent, no additional interviews were conducted.

10.6 FACTOR INTERPRETATION & CREATION OF NARRATIVES

The final step in Q-methodological research is the interpretation of the factors and the creation of narratives based on these factors. The three identified factors consist of a factor loading on each statement. Moreover, each factor contains information about which of the respondents has loaded significantly on the factor. The list of factor loadings was converted into a crib-sheet. A crib-sheet indicates which factors are ranked +5 or -5, moreover the crib-sheet indicates which of the statements were ranked higher or lower in this factor than in the other factors. Watts & Stenner (2012) advice the use of crib-sheets to ensure a holistic interpretation of the factor arrays. Appendix 11 contains the crib-sheets for the identified three factors. Moreover, the respondents 'comments on the sorting process were used to support the interpretation of the factors and illustrate the respondents' perspectives. The results of the interpretation of the factor-arrays are discussed in chapter 11.

10.7 CONCLUSION

In this chapter we have answered the sub-question: *How can municipalities identify the perspectives of residents on the process of the phase-out of natural gas?*. We have applied Q-methodological research on a case study in Zoetermeer, to identify what steps municipalities need to take to identify the perspectives of residents on the process of the phase-out of natural gas. Four main takeaways for the application of the Q-methodological research method that can be derived from the case study are:

1) The review of existing grey-literature on resident perspectives on the phase-out of natural gas provides useful and sufficient inputs for a structured Q-sample. None of the respondents indicated that they were missing any topics within the Q-sample. Moreover, all relevant aspects of the perspective of residents on the phase-out of natural gas that were derived from the set of statements are represented. Therefore, a structured Q-sample, based on a grey literature search can provide a relevant Q-sample. However, even after extensive evaluation by different parties, the list of statements still contained some unclear or double statements: specifically statement 16, 19 and 36. It necessary to be careful when interpreting these statements in the factors and to fall back on the responses of the respondents.
2) The interviews and the subsequent steps in the factor analysis have resulted in the identification of three perspectives. However, the eigenvalues of the factors and the factor-loadings indicate that no saturation of the data has taken place. This means that there is insufficient data to draw conclusions about the finite number of diverse perspectives that exist on the phase-out of natural gas within the respondent pool. This indicates that additional interviews can result in a different number of perspectives. Moreover, the composition of the statements within each perspectives could change when adding more Q-set. This means that to identify the finite set of perspectives, it may be necessary to apply a different method for sampling the respondents or to research a larger sample size.
3) The current respondents varied with regard to, age, gender, home ownership, education level, income level, awareness of the transition and existing sustainable home improvements. There were no respondents with an income below modal, nor were there any respondents with an education level of VMBO/MAVO or lower. There is no correlation between the described characteristics of the respondents and the identified perspectives. This may change if there is data-saturation. However, for now we do not know if or how we could generalize the perspectives to the population. Additional research (for example a questionnaire) would be necessary to determine the distribution of the perspectives throughout the population.
4) The respondents took their participation in the Q-study seriously. The respondents were satisfied with the resulting ordering of the statements and had a positive attitude towards the process. Moreover, we have seen that the respondents have experienced the participation in the study as a first step in the communication-and-decision making process that either raised awareness or triggered more questions.

In chapter 11 we will interpret the identified factors and create narratives on the phase-out of natural gas and we will asses the relevance of the research results in a focus group with policy makers and communication professionals of the municipality Zoetermeer, who are currently engaged in designing a communication-and-decision-making process for the phase-out of natural gas.

11.

THE RELEVANCE OF RESIDENT PERSPECTIVES ON THE PROCESS OF THE PHASE-OUT OF NATURAL GAS

What is the relevance of the perspectives of residents on the process of the phase-out of natural gas for designing effective communication-and-decision making processes in the heat transition?

In chapter 10, we have discussed how we have applied Q-methodology to identify resident perspectives on the process of the phase-out of natural gas. In this chapter, the results of this research are discussed. The Q-methodological research provided three different types of insights. Firstly, it provides insights in what statements are evaluated in a similar manner by all respondents. Secondly, it provides insights in what statements are evaluated in a distinctively different manner by all respondents. Thirdly, it provides insights in the resulting perspectives of residents on the process of the phase-out of natural gas. This chapter starts with the discussion of similarities (11.1) and differences (11.2) between the perspectives. Then these perspectives are individually discussed (11.3). Since we are looking to establish whether Q-methodology can provide relevant information for municipalities for designing governance between residents and municipalities in this transition, we will discuss these perspectives with policy-makers and communication employees from the municipality of Zoetermeer in a focus group (11.4). We will conclude on the relevance of applying Q-methodology for developing a communication-and-decision-making process about the phase-out of natural gas (11.5).

11.1 SIMILARITIES BETWEEN THE PERSPECTIVES

The first step in exploring the results from the Q-methodological research is the evaluation of the similarities between the perspectives. For 18 of the 58 statements, there is no significant difference in how the statements are valued in the different factors. This indicates that there is agreement among the participants with regard to these statements. Textbox I provides an overview of these statements. The statements are both process and content related. Six out of these 18 statements, were highly commented on during the interviews. This indicates that the respondents clearly had an opinion on the statement; however, the opinion is shared among the different identified factors and can therefore not be attributed to a single perspective. These six statements are discussed in 11.1.1 – 11.1.5. 11.1.6 contains insights on the relevance of these insights for the design of governance for the heat transition.

TEXTBOX IV: CONSENSUS STATEMENTS

Agree:

- ✓ Ik vindt het belangrijk dat de plannen voor aardgasloos wonen in mijn wijk flexibel blijven zodat toekomstige innovaties daarin kunnen worden opgenomen.
- ✓ Het is belangrijk dat energie toegankelijk blijft voor mensen met een laag inkomen. We moeten hen beschermen tegen hoge kosten.
- ✓ Als we aardgas gaan vervangen wil ik er zeker van zijn dat het alternatief de beste optie voor het milieu is.
- ✓ Als mijn wijk aan de beurt is, en alles is goed geregeld, dan wil ik best meegaan en overstappen op aardgasloos wonen. Maar ik wil er zelf zo min mogelijk tijd en moeite in steken.
- ✓ Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken.
- ✓ Ik vind het belangrijk dat in gesprek kan gaan met mijn buren over de overgang naar een aardgasloze wijk.
- ✓ Lokale energie initiatieven en wijk gebonden bewonersorganisaties moeten intensief betrokken worden in de besluitvorming over aardgasloos wonen op wijk niveau.
- ✓ De gemeente moet mij ondersteunen in het keuzeproces over het vinden van het juiste alternatief voor aardgas.
- ✓ Wijkbewoners en de gemeente kunnen van elkaar leren als het gaat over aardgasloos wonen.
- ✓ De gemeente kan me helpen om de juiste specialisten te vinden en (indien nodig) vergunningen te regelen om aardgasloos te gaan wonen.

Disagree:

- × Technologische veranderingen gaan snel. Het is onzin om nu al na te denken over hoe mijn wijk of huis aardgasloos kan worden.
- × Wonen zonder aardgas is ingewikkeld en ik weet niet hoe ik daar aan moet beginnen.
- × Algemene technische berekeningen over rendementen en kansen doen geen recht aan de impact van aardgasloos wonen op mijn leven.
- × Aardgasloos wonen zorgt voor een hoop rommel en gedoe, en uiteindelijk schiet ik er niks mee op.
- × Als aardgas wordt vervangen door een lokale energiebron dan levert dat economische kansen en werkgelegenheid op in mijn directe omgeving op.
- × Het uitfaseren van aardgas biedt een kans om de afhankelijkheid van grote energiebedrijven te verminderen en de energievoorziening lokaal en eerlijker vorm te geven.
- × Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen.
- × Ik voel mijzelf en mijn woonwensen over aardgasloos wonen door lokale energie initiatieven en wijk gebonden bewonersorganisaties goed vertegenwoordigd.

11.1.1 FLEXIBILITY TOWARDS INNOVATIONS

"Ik vindt het belangrijk dat de plannen voor aardgasloos wonen in mijn wijk flexibel blijven zodat toekomstige innovaties daarin kunnen worden opgenomen." – Statement 21

This statement is about the flexibility of the transition-plans towards future innovations. It is a content-statement, related to the value of improvements of quality of life. In all three perspectives, this statement is moderately important (+2,+3). Three respondents commented that the transition is still in a very early stage. There is a lot yet to be discovered about the transition and its technical solutions, and technical innovations go fast. This means that the options can change over time, or they can become more (cost-) efficient than they currently are. According to these respondents, it is therefore important that we stay flexible with regard to the available options and do not create a lock-in. One respondent agreed with this statement, but also indicated that it is important that we able to make decisions at a certain stage, we should not continue testing new options endlessly. Moreover, there is one important outlier with regard to the assessment of this statement. One respondent, who values the statement as +6, strongly believes in technological innovations, especially with regard to heat-pumps. He suggests to start with no-regret options, such as better insulation. He suggests waiting for better technologies before replacing existing systems. He summarises his attitude towards this transition in the following quote:

"De duurzaamheid van vandaag mag de innovaties van morgen niet voor de voeten lopen"

11.1.2 SHORT-TERM DISCOMFORTS

"Aardgasloos wonen zorgt voor een hoop rommel en gedoe, en uiteindelijk schiet ik er niks mee op." – Statement 24

This statement is about the short-term discomforts residents may experience from the transition, and how this relates to the perceived benefits from the transition. It is a content-statement, related to the value of improvements of quality of life. Most respondents have indicated that they are not worried about the potential discomfort that will come from replacing the natural gas infrastructure with a different infrastructure for heating. Especially out-door works are regarded as a necessary but temporarily discomfort that is easily overcome. The experiencing of discomfort serves the greater good, of a natural gas free heating system and this discomfort is proportionate. However, indoor renovations are assessed differently, especially when the respondents can project the renovations on their own home-environment. When the renovations are limited to within the fuse-box, again no opposition can be expected based on the respondents comments and responses. However, when the renovations have an impact on the home-environment, some respondents have indicated to oppose this.

One respondent linked low-temperature heating systems with the necessity to place an under-floor heating system, which would mean that he would have to replace his new hardwood floor. The same respondent indicated that he would not be willing to replace his beautifully maintained high-end stove. He stated he would rather purchase a reservoir for cooking gas. The same respondent was also not pleased with the fact that his 82-year-old mother, who finds great joy in cooking, would have to re-learn how to cook on a different type of stove, and replace all her pots and pans, which she has collected over the years. In addition, another respondent mentioned that her rental home will be extensively renovated in the near future, meaning that she would have to temporarily leave her home. While her home would be more comfortable (double-glazing and better insulation) and more safe (removal of asbestos) after the renovations, this still caused her great discomforts.

11.1.3 PROTECTION OF FINANCIALLY VULNERABLE

"Het is belangrijk dat energie toegankelijk blijft voor mensen met een laag inkomen. We moeten hen beschermen tegen hoge kosten." – Statement 28

This statement is about the expected costs associated with the transition, and responsibility society should take with regard to protecting financially vulnerable groups against these costs. This is a content-statement related to the value of social justice and fairness, however it could also be related to the value of safe, reliable and accessible. The statement is related to the concept of energy-poverty, which indicates the lack of access to modern energy facilities. In all three perspectives, this statement is labelled as moderately to very important (+3, +4, +5). All respondents agree that energy should be affordable for everyone. However, the principles underlying this choice vary among the participants. Two respondents explicitly advocate a fair distribution of costs, based on income, as a means to reduce inequalities. Where one respondent mentions the support base for the overall transition as an important reason to keep the transition affordable for everyone. Socialization of costs was often indirectly implied, sometimes with references to historically similar transitions. Such as the transition from coal to city-gas and the transition from city-gas to Groningen-gas.

11.1.4 INDIVIDUAL FINANCIAL INVESTMENTS

" Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen." – Statement 31

This statement is about the expected costs associated with the transition, and the willingness of the respondent to directly contribute to the phase-out of natural gas financially. This is a content-related statement and is related to the value of safe, reliable and accessible. In all three perspectives, this statement is ranked close to neutral (1,-1). However, the respondents have heavily commented on the statement. Most respondents indicated that they find it difficult to invest by themselves. They are afraid that high initial individual investments will result in opposition towards the transition. Moreover, the respondents that have indicated that they would be willing to invest by themselves want insights in the financial benefits of their investment. Both in terms of their monthly energy bill and in terms of the value of their house. Homeowners perceive their house as their most expensive asset, or their highest debt. They are risk-averse with regard to changes to this asset. Moreover, respondents have commented that investing in their house means that they have less financial freedom to uptake other projects. Therefore, it is not purely a financial investment, but a trade-off in terms of quality of life. Freedom of choice is frequently mentioned in relation to this statement. Most respondents have indicates that when individual financial investments are necessary, they want to make the final decision themselves.

11.1.5 INDIVIDUAL EFFORTS

"Als mijn wijk aan de beurt is, en alles is goed geregeld, dan wil ik best meegaan en overstappen op aardgasloos wonen. Maar ik wil er zelf zo min mogelijk tijd en moeite in steken." – Statement 36

"Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken." – Statement 39

These statements are about the individual efforts respondents have to put into the process of the transition. These are process-statements and relate to the desired level of participation of the respondent. The respondents have commented on statement 36 and 39 in a similar manner. In all three perspectives, these statements are ranked close to neutral or moderately agree (2, 1, 0,-1). Most respondents have indicated that the transition is not part of their daily concerns. They are not the front-runners in this transition. However, when the phase-out becomes current in their district, all respondents are willing to put in the necessary time to make sure a right decision is made. Some respondents have indicated that they would want to take-part in neighbourhood-level discussions about the right alternative. Others foresee a more individual role for themselves, focussed on information gathering. These individual statements will be further explored in the discussion of the different perspectives.

11.2 DIFFERENCES BETWEEN THE PERSPECTIVES

The second step in exploring the results from the Q-methodological research is the evaluation of the differences between the perspectives. In this section, the main differences between the perspectives are highlighted. These differences, together with the crib-sheets in appendix 11 form the basis of the narrative of the perspectives, which are discussed in section 11.3. The differences between the perspectives are discussed in terms of 1) the problem perception (11.2.1), 2) the desired content of the process (11.2.2) and 3) the desired process design (11.2.3).

11.2.1 DIFFERENCES IN PROBLEM PERCEPTION

The perspective on the process of the phase-out of natural gas in the three perspectives differs with regard to the problem perception. Statement 1 to 18 are about the individual's perception of the transition and the conditions under which he or she is willing to take part in the transition. The topics included in this perception are: knowledge about the transition, innovativeness of the resident: desires with regard to the timing and phasing of the transition, attitude towards the national and local transition objective, current level of self-efficacy, attitude towards decision-making under uncertainty and trust in the municipality. Table 46 shows an overview of how these statements are valued in the different perspectives. The high z-scores indicate that the statements are valued differently in the different perspectives. Low z-scores indicate similarities. A z-score of zero means that the statements are evaluated exactly the same among the three perspectives. A z-score of three or larger indicates a real outlier. The main differences between the perspectives are about:

1) the innovativeness of the respondent and the risks associated with a fast transition (6),
2) the self-efficacy with regard to decision-making (7),
3) the problem perception and the necessity of the transition based on issues frequently associated with the transition (10),
4) the attitude towards the national transition objective and the perceived forcefulness of the transition (12) and,
5) the attitude towards the national transition objective and the distance between the government and the public in the formulation of transition objectives and organization of the transition (13).

Table 45 Interpretation of statements with regard to the perception of the transition

#	Content	Score perspective 1	Score perspective 2	Score perspective 3	z-score
Innovativeness of respondent: timing and phasing of transition					
1	Nonsense to think about the transition already	-4	-2	-3	0,189
2	Early communication is necessary, even under uncertainty	4	6	0	0,562
3	The right moment to transition, is when you move houses	0	-4	-6	0,587
4	Transition needs an early start and small steps	-1	1	3	0,308
5	We are addicted to fossil fuels and should stop using them immediately	-3	-2	-6	0,345
6	Fast transition results in failure	-3	-3	5	1,287
Self-efficacy					
7	I do not know enough to make a decision.	0	2	-4	0,805
8	I do not know how to start this transition.	-4	-4	-1	0,146
9	I can organize the phase-out of natural gas for my house myself.	-2	0	-5	0,433
Problem perception					
10	Societal issues make transition a necessity	4	-1	6	0,832
11	Natural gas is relatively affordable and clean	-2	-2	1	0,249
Attitude towards the local and national transition objective					
12	The transition is forced upon residents	-6	-3	-1	0,946
13	Distance between ambitions of the government and the public is too large	-3	4	0	0,915
14	The transition is driven by left-wing politics	-5	-5	-2	0,263
15	Certainty about financial impact	5	1	5	0,443
16	Individual decisions have no real impact	0	-4	-2	0,334
17	Natural gas is necessary	-6	-6	-3	0,328
18	Start as soon as possible.	0	2	-3	0,455

11.2.2 DIFFERENCES IN DESIRED CONTENT

The perspective on the process of the phase-out of natural gas in the three perspectives differs with regard to the desired content. Statement 19 to 35 are about the individuals values with regard to the transition and the resulting heating system. The categories of values are: improvement of quality of life, social justice and fairness, autonomy and power, security and stability and protection of environment and nature & efficient and not wasteful. Table 47 shows the factor-scores in the different perspectives and the z-scores per statement. The main differences between the perspectives are about:

1) the desirability of improvements to the neighbourhood when the streets are opened-up for changes to the infrastructure (22),

2) the expectations towards and desirability of independence of large energy companies (29), and
3) the expected safety and reliability of alternatives for natural gas (34).

Table 46 Interpretation of statements with regard to the content of the process

Value		Score perspective 1	Score perspective 2	Score perspective 3	z-score
Improvement and quality of life					
19	Reluctance towards technocratic decisions	-2	-2	-1	0
20	Sensitivity towards the behavioural impacts of the transition	1	0	-1	0,182
21	Flexibility towards future innovations	3	3	2	0,018
22	Improvements to the neighbourhood	1	5	-2	0,909
23	Improvements to home comfort	-1	-3	3	0,546
24	Discomfort of short-term chaos	-5	-6	-4	0,123
Social justice and fairness					
25	Responsibility towards future generations	3	6	2	0,263
26	Local economic opportunities	-1	-1	0	0,015
27	Valuation of self over society	-3	-1	1	0,188
28	Protection of (financially) vulnerable	6	3	4	0,075
Autonomy and power					
29	Independence of large energy companies	0	-3	4	0,861
30	Control over in-house system modifications	-3	-2	-2	0,025
Security and stability					
31	Financial commitments	-1	-1	1	0,054
32	Improved safety	2	1	-3	0,526
33	Expected financial gains	1	0	-1	0,264
34	Expected safety and reliability	6	-1	-3	1,326
Protection of environment and nature & efficient and not wasteful					
35	Improvements in sustainability	3	5	5	0,08

11.2.3 DIFFERENCES IN DESIRED PROCESSES

The perspective on the process of the phase-out of natural gas in the three perspectives differs with regard to the desired organization of the process. Statement 36-58 are about the desired organization of the process of the phase-out of natural gas in a neighbourhood. The categories included are: desired level of participation, desired inclusion of stakeholders, stakeholder roles and desired prospective outcome. Table 48 shows the factor-scores in the different perspectives and the z-scores per statement. There are two main difference between the perspectives with regard to the organization of the process:

1) the prerequisite for the transition that companies and industries also participate (40) and,
2) feelings about the way the timing of the transition should be organized (52).

Table 47 Interpretation of statements with regard to the process organization

		Score perspective 1	Score perspective 2	Score perspective 3	z-score
Level of individual participation					
36	Individual effort	2	1	-1	0,132
37	Inclusion of professionals and experiential experts.	-1	2	4	0,401
38	Visitation of experiential expert at home.	-2	3	-1	0,685
39	Priority	0	0	2	0,065
Desired inclusion of stakeholders					
40	Inclusion of industry and companies.	5	0	6	0,95
41	Inclusion of neighbours	1	2	0	0,09
42	Inclusion of local energy initiatives and resident associations	1	2	3	0,059
43	Representation through local energy initiatives and resident associations	-1	-2	-1	0,018
Influence and equality among participants					
44	Resident and municipality are equal partners	0	3	1	0,239
45	Municipality and the province actively collaborate	4	4	1	0,112
46	Municipality invites relevant parties	3	0	2	0,223
47	Municipality supports individual decision-process	2	1	2	0,034
48	The municipality has sufficient expertise	2	-1	-4	0,449
49	Early inclusion of residents: before investigation of alternatives	-2	3	1	0,405
50	Central government makes the transition mandatory	2	-3	0	0,592
Desired outcome					
51	Individual decision mandate	-1	4	0	0,513
52	Municipal timing mandate	3	-5	0	1,461
53	Collective and democratic decisions	-2	1	2	0,229
54	Mutual learning	2	1	1	0,043
55	Social and cosy process	-4	0	-5	0,566
56	Access to experts	1	0	0	0,005
57	Financial support	0	-1	3	0,296
58	Independent information inquiry	1	2	-2	0,382

11.3 PERSPECTIVE NARRATIVES

In section 11.1 and 11.2, we have discussed the similarities and differences between the perspectives. We have seen that the research has resulted in the identification of three distinctive perspectives on the process of the phase-out of natural gas: Perspective 1: The municipality takes the lead, the whole society follows (10.3.1), Perspective 2: Individual decisions for a green, clean future for the next generations (10.3.2) and perspective 3: Waiting for technological progress (10.3.3). In this section, we will discuss these different perspectives in more detail. The descriptions of the perspectives are in narrative style, as recommended by Watts and Stenner (2012). The narratives are told from a first-person perspective. The descriptions of the perspectives consist of a perception of the transition, the important values within the transition, and the desired process design. The statements from these three different categories are sometimes linked to each other, because respondents have linked these statements in their interviews.

11.3.1 PERSPECTIVE 1: THE MUNICIPALITY TAKES THE LEAD, THE WHOLE SOCIETY FOLLOWS.

Factor 1 has an eigenvalue of 3.9 and explains 28% of the study variance. Six participants are significantly and uniquely associated with this factor. Their socio-economic characteristics vary greatly. Based on the data collected about the respondents, no common denote was found. The perspective is based largely on the q-sort of a female tenant in the age of 40-60, with a HBO/WO-bachelor education level and an income slightly above modal. The q-sorts of two out of the three tenants loaded significantly and uniquely on this factor. The third tenant has recently purchased a home and loaded significantly on both factor 1 and factor 2. This could indicate that this perspective is shared among tenants. Moreover, the q-sorts of three out of five people with a WO-master or higher education load significantly on this factor. The factor explains between 88% and 59% of the common variance of the individual perspectives.

PERCEPTION OF THE TRANSITION

The earthquakes in Groningen, the increasing dependence on Russian gas and the climate, make the phase-out of natural gas an urgent matter (10: +3). Our society does not need natural gas to function properly (17: -6). The phase-out of natural gas it is the answer to several societal problems, which we have to solve together, not a left-wing political idea (14: -5) that we are all forced to corroborate with (12: -6). As such, the process of the phase out of natural gas should start rather sooner than later (18:0, 4: -1, 6: -3).

"Er wordt eindelijk een beetje ambitie getoond."- Respondent 1

"Bij veranderingen zijn er altijd dingen die er achteraf beter kunnen gaan, dat moet je incalculeren… Gewoon [mee gaan in de verandering] wanneer je aan de beurt bent." – Respondent 5

VALUES

The broad uptake of the transition is of the utmost importance. Individual efforts will not have sufficient impact (16:0). In addition, it is undesirable if only households corroborate. The industry and companies will have to invest in the transition too. When this broad uptake is lacking, I am not willing to participate in the phase-out of natural gas (40: +5). It is very important that the (financial) burdens are fairly distributed among members of society, based on individual capacities. Moreover, throughout the transition energy should stay accessible and affordable for everyone, including low-income families (28: +6).

DESIRED PROCESS

While the municipality should facilitate this broad uptake, the central government should support municipalities in realising this, by obligating the phase-out of natural gas nationally (50: +2). The municipality has sufficient expertise to guide the phase-out of natural gas (48: +2) or can hire the right professionals. It is however, key that the municipality involves the right stakeholders, including housing associations, installers, contractors, local industry, greenhouse owners and residents (46: +3). The municipality should stay in close contact with the Province of South Holland to align local and regional plans (45: +4). This is necessary to avoid inequalities between municipalities, and select regionally optimal alternatives for natural gas. Regional optimal choices are more important than selecting the optimal alternative for natural gas for individual houses (27: -3).

"Ik ben heel erg coöperatief ingesteld, dus als een collectieve oplossing echt beter is voor mijn buurt dan ga ik daar waarschijnlijk in mee." – Respondent 1

ORGANIZATION

The phase-out of natural gas is not an individual process! Collective and democratic decisions and individual mandate are not necessary in this transition (53: -2, 51: -1). Moreover, it is not necessary that the municipality involves me personally in the decision-making process for my district (44:0). I do believe that the municipality and residents can learn from each other in the process towards gas-free districts (54: +2). However, it is nonsense that social and cosy processes are necessary for me to maintain the feeling of home (55: -4). A good option would be to involve local energy initiatives and district-specific resident organizations (42: +1). However, if they would be involved, it is necessary that they are in better contact with the residents within my district. As currently, I do not feel that these organisations can truly represent me with regard to my needs in this transition (43: -1). Mostly, because I do not know who they are.

"Ik heb er behoefte aan dat ik kan wennen aan het idee dat we van het aardgas af gaan. Dan kan ik me een beetje gaan inlezen en dan komt het niet zo plompverloren op je bord." – Respondent 5

It is necessary that the process is transparent and that the municipality communicates in an early stage (27:+4). A good moment to start communicating would be when the alternatives for natural gas in my district are known. For me it is important that I know which options are available, and that I can understand the choices that are being made. I don't really value interactions with professionals and experiential experts (38: -2, 58: +1). However, I find it important that I can have easy access to the information whenever I am willing to read-up on the process and the options for the changes at hand.

11.3.2 Perspective 2: Individual decisions for a green, clean future for the next generations

Factor 2 has an eigenvalue of 0,8 and explains 8% of the study variance. Two participants are uniquely significantly associated with this factor. They are both male home-owners in the ages of 40-60 and 60-80. Their education level is HAVO/VWO/MBO and HBO/WO-bachelor and they have a modal, or above modal income. The perspective is based largely on the q-sort the older male home-owner in, with a HAVO/VWO/MBO education level with a modal income. A third respondent loaded not uniquely but significantly on this factor, with by far the highest value on this factor. This is the tenant who recently purchased a new home. Sustainability was an important factor in her decision; she purposefully purchased a house with a heat pump. She has a HBO/WO-bachelor and a modal income. The factor explains between 89% and 76% of the common variance of the individual perspectives.

Perception of the transition

The phase-out of natural gas should be finished rather sooner than later (18: +2). We can definitely do without natural gas (17: -6). By renovating my house and phasing-out natural gas, I contribute to a green and clean living environment for the next generations (25: +6). I find that very important, especially for my children and/or grandchildren. Moreover, I believe that natural gas is unsafe (32:+1). Firstly because of the earthquakes in Groningen and secondly because of the dangers of natural gas inside the house. We should not want to continue to use natural gas in households. However, I am not certain that currently, the alternatives for natural gas are currently sufficiently developed to supply heat in a safe and reliable manner (34: -1). In addition, I feel that the central government is currently too ambitious with regard to the phase-out of natural gas (13: +4).

"Wat is nou voor mij het beste passend. Ik wil daarin niet per se alleen een financiële afweging maken. Maar hoe langer ik er over nadenk... Ik denk dat duurzaamheid en zekerheid daarin ook een belangrijke rol spelen. Ja ik wil daar wel een eigen keuze in kunnen maken. Liever dan dat de gemeente dat bij mij oplegt." – Respondent 7

Values

It is very important for me, that when natural gas is phased-out, I am certain that the cleanest alternative is selected that is both technically and financially possible (35: +5). Still, I do have financial concerns. I would like to financially benefit from these changes, especially when I have to invest by myself. However, I would be willing to spend some money on this transition (31: -1). I am not convinced that after the renovation my house is more comfortable than it is now (23: -3), however I also do not expect any discomforts. I do not particularly value cooking on or heating with natural gas, as the alternatives can become just as good (29: -3). I also find it important that when natural gas is phased-out in my district, and streets are opened up, this opportunity is used to improve the neighbourhood: improved landscaping, benches, problems with young people, street lighting, loneliness etc. (22: +5). The transition should be an improvement of quality of life, for current and next generations.

"Ik wil niet inleveren op wooncomfort. Dat vind ik heel erg belangrijk. Maar ik weet dat het ook op een andere manier kan." – Respondent 10

Desired process

I currently know insufficient of the alternatives for natural gas to make an informed decision for my own home (7: +2). However, I find it very important that I have the final say in the decision for an alternative for natural gas in my house (51:+4). I currently do not feel like this transition is forced upon me (12: -3), but I can imagine that if the transition is obligated by the central government, or the municipality, my perception will change. I do not think obligations are the answer to realizing the transition (50: -3). Moreover, I would not accept it if the municipality would decide when natural gas is phased-out in my district (52: -5). My decision however, does not depend on the efforts of others towards the transition. Even when industry and companies are not participating in the transition, I would be willing to make the change (40: 0). Moreover, I am also willing to comply with collective alternatives for natural gas, such as district heating, but it should always be my own choice (27: -1). Local energy initiatives and resident organisations can play a role in the process (42:+2), however, I currently do not feel like they truly represent me with regard to my needs in this transition (43: -2).

"In mijn nieuwe huis zit straks een warmtepomp. Daar is een apart kamertje voor gemaakt op zolder. Een warmtepomp is ongeveer zo groot als deze boekenkast. Ik ben wel benieuwd hoe mensen die een warmtepomp hebben dat ervaren."- Respondent 10

ORGANIZATION

The phase-out of natural gas relies on individual decisions, especially when it comes to homeowners. However, the municipality can take an overarching and facilitating role in the process. I would prefer a social (and cosy) process; however, it is not a necessity (55: 0). The process should be highly transparent and communicative. I want that the municipality approaches me as an equal partner in the decision making process about my house and/or direct neighbourhood (44: +3). The municipality should definitely not start evaluating alternatives for natural gas in my direct environment before informing me, then I would feel passed (49: +3). The municipality however, can organize knowledge exchange and development on this topic. I believe that the municipality and residents can learn from each other when it comes to this transition (54: +1). However, personally, I would value interactions with professionals in the field and experiential expects more (37: +2). Moreover, I would like to be able to visit some model-homes to experience the impact of the indoor changes (38: +3). In addition, it would be handy if there would be an independent organization where I could gather information and ask questions (58: +2).

11.3.3 PERSPECTIVE 3: WAITING FOR TECHNOLOGICAL PROGRESS

Factor 4 (perspective 3) has an eigenvalue of 1 and explains 7% of the study variance. Three participants are uniquely and significantly associated with this factor, one participant is uniquely associated with this factor, however the factor loading is slightly too low to be significant. The socio-economic characteristics of the respondents associated with this factor vary greatly. Based on the data collected about the respondents, no common denote was found. Moreover, the awareness of the transition and the presence of historic sustainable home improvements varies among the respondents. However, two out of the three associated respondents have a background in installing technique. One in a coordinating function in an industrial setting and one as a legal expert and engineer for residential heating systems. The factor is mostly based on the q-sort of a male home-owner in the age of 40-60, with a background in installing technique. The factor explains between 93% and 52% of the common variance of the individual perspectives.

PERCEPTION OF THE TRANSITION

The earthquakes in Groningen, the increasing dependence on Russian gas and the climate, make the phase-out of natural gas an urgent matter (10: +3). And reducing the use of natural gas will contribute to a greener an cleaner living environment for the next generations (25: +2). However, I am not entirely sure if we can currently do without natural gas (17: -3). Moreover, natural gas cheap, comfortable and relatively clean (11: + 1).

"Ik zou hier niet in de kou willen zitten en denken "had ik nou maar aardgas"." – Respondent 12

There is sufficient natural gas left on this planet to realize the phase-out of natural gas gradually. I certainly don't think we should rush the phase-out (5: -6, 18: -3). This process requires that we think in small steps and start as soon as possible (4: +3, 1: -3). However, we need to take time for this transition to organize it in a neat way. Especially because companies are not ready yet. There are insufficient well-educated and trained installers. Besides this, the alternatives for natural gas are not developed enough to be a safe and reliable alternative to natural gas (34: -3). Also, time will lead to increasing (cost-) efficiency of the available options. Decisions about the phase-out of natural gas should therefore remain flexible towards future innovations (21: +2). "The sustainability of today should not impede the potential of the innovations of tomorrow."

"Het proces is technisch inhoudelijk. Je moet het zo inrichten dat je achteraf geen spijt krijgt. Technische ontwikkelingen hebben enorme perspectieven. Ik voeg liever dingen toe, dan dat ik echt ga verbouwen, vervangen en inbouwen." – Respondent 14

VALUES

I want the best alternative for natural gas for my own house, even when this means that my decisions impede opportunities to realize the optimal solution for my neighbourhood or district (27: +1). I highly value my autonomy with regard to deciding how I cook and heat my house (29: +4). However, the decision about an alternative for natural gas is for me not about new equipment for heating and cooking and the additional behaviour changes (20: -1). The decision should be about selecting the best option for the environment (35: +3), which technically and financially fits my house best. The decision should be supported by calculations and quantitative data (19: -1). Actually, I am not willing to pay more for, or invest in, a gas-free heating system (31: +1). However, I do think heating will become more expensive, when we start with the phase-out of natural gas now (33: -2). That said, I am not sure if I would go along with the transition, if my district would be the next district where natural gas would be phased-out (36: -1).

"Maatregelen moeten bij je portemonnee passen. Installateurs zijn vaak niet goed op de hoogte. Het is een ellende als je alleen gaat isoleren, maar de installatie achter blijft. Je moet goed inregelen." – Respondent 14

Fully renovated, houses without natural gas are more comfortable than houses without these renovations (23: +3). However, the phase-out of natural gas is not a prerequisite to renovate houses. Better insulation, double-glazing etc. are no-regret options, which should be encouraged in the first stage of this transition. The government should provide financial incentives to take steps towards a natural gas free house, such as subsidies or tax-advantages (57: +3). Only when I have financial certainty, I am willing to invest (15: +5).

DESIRED PROCESS

I am currently unable to organize the phase-out of natural gas in my own home (9: -5). Besides this, living without natural gas is not really at the top of my priority list (39: +2). I only want to phase-out natural gas in my house if everyone participates in and pays for the transition. This should include the industry and companies (40: +6). The municipality has insufficient expertise to organize the phase-out of natural gas in the right way (48: -4). This opinion is based on previous experiences with the municipality. Therefore, the municipality should attract knowledgeable parties, which together can make informed decisions about the transition (46: +2). It is important that residents are represented in this group, as the municipality and residents can learn from each other (54: +1), however I do not necessarily want to be involved personally. I don't need a social process (55: -5). Nor do I feel the need to engage with my neighbours on this topic (41: 0). Local energy initiatives and resident associations should be involved instead (42: +3). I know these organizations; however, I do not trust that they truly represent me with regard to my needs in this transition (43: -1). This should be improved.

ORGANIZATION

I believe that the right process can lead to the right decisions. Therefore, it does not really matter who has the mandate to decide which alternative for natural gas is selected, or when natural gas is phased-out (50, 51, 52: 0). It does however, matter that I have trust in the organisations that are involved in the process. In addition, I want that the majority of the residents in my neighbourhood supports the choices made (53: +2). I want to be well informed about the process and content of the decisions at hand. The municipality should communicate in an early stage of the process, preferably before they start to investigate which alternatives for natural gas are available in my neighbourhood (49: +1). If I don't trust the process, or if I feel like I am being forced into investments or changes that I don't support, I will object.

11.3.4 INSIGHTS

The narratives of the perspectives can provide coherent stories on how residents may perceive the transition process, in terms of problem perception, desired content of the discussion and desired process design. However, we have also acquired individual stories related to the transition which help understand the local or even personal context of the transition (textbox V). To determine if these narratives can be used as a starting point for designing a communication-and-decision making process, a focus group is organized with policy-makers and communication experts from the municipality Zoetermeer, who are currently involved in developing a communication-and-decision-making process for the phase-out of natural gas in the district Palenstein in Zoetermeer. This focus group is discussed in 10.4.

TEXTBOX V: PERSONAL STORIES REGARDING THE TRANSITION

"Mijn buren en ik verwachten dat de aardgasleiding door het achterste deel van onze tuin loopt. Dit is een stuk tuin dat we ons zelf hebben toegeëigend, maar dat waarschijnlijk officieel niet van ons is. Ik ben bang dat als de gasleiding opgegraven wordt, ik mijn tuinhuisje kwijt raak dat op dit stukje tuin staat. Ook heeft de gemeente net twee mooie bomen voor mijn huis weggehaald. Ik heb er geen vertrouwen in dat de gemeente mijn fijne "groene" omgeving echt gaat verbeteren." – Respondent 1

"Je moet net als bij stadsgas mensen een alternatief bieden. Ik kan het me nog goed herinneren, ik was toen een jongetje. Iedereen kreeg toen een nieuw fornuis en een nieuwe ketel. Dat was feest."- Respondent 3

"Waar ik ben opgegroeid (Schoonenbeek) was de NAM belangrijk voor de gemeenschap. Mijn zus en mijn zwager hebben beiden voor de NAM gewerkt. Het is een goede werkgever en de NAM heeft voor de bewoners van Schoonenbeek voor veel goeds gezorgd." – Respondent 4

"We hebben hier nieuwbouw van de school, daar zijn we een keer bij betrokken en dat komt binnenkort nog wel een paar keer. En dan zijn we met elkaar en kunnen we nadenken over hoe we het willen hebben. Dat helpt wel. Dus een sociaal proces, dat gezellig is wat anders, maar ja dat vindt ik wel belangrijk.."- Respondent 7

"Ik wil graag meedenken over wat de beste optie is voor deze wijk. Maar in kaart brengen is prima. Onze huizen worden gerenoveerd en daar hebben we ook per straat een aantal keuzes in gekregen. Dan kon je via de mail doorgeven wat je wilde. Uiteindelijk geldt de stem van de meerderheid. We hebben ook inzicht gekregen in welk deel van de bewoners wat heeft gestemd. Uiteindelijk is het niet geworden wat ik graag wilde, maar dat is oké, omdat ik weet dat er wel goed naar de bewoners geluisterd is."- Respondent 10

"Verplichten is nooit goed in dit soort zaken. Je kan mensen niet vragen om teveel of te grote veranderingen te ondergaan op het moment van een ander. Als ze aardgasnetten niet gaan vervangen, [en dat als drukmiddel gebruiken om van het aardgas af te gaan] dan verzaakt de overheid. Als ze dat gaan doen dan ben ik instaat om een gastank in mijn kelder te zetten. Mijn moeder van 82 woont in Palenstijn… hoe denk je dat dat voor haar is, als ze nu van het aardgas af moet." – Respondent 12

11.4 FOCUS GROUP: REFLECTION ON PERSPECTIVES

To evaluate the relevance of the perspectives for designing a communication-and-decision-making process by municipalities, we have performed a focus group. A focus group is a qualitative research method, used to investigate thoughts, ideas, motives and interests with regard to a predetermined topic. In 11.4.1 we will discuss the organization of the focus group. In 11.4.2 we will discuss the content of the focus group, in 11.4.3 we will discuss the outcome of the focus group. In 11.4.4 we will present a conclusion on the relevance of the identified perspectives for the design of a communication-and-decision-making process in the municipality Zoetermeer.

11.4.1 ORGANIZATION

The focus group took place on the 29th of March in the city hall in Zoetermeer. The focus group has taken place in Zoetermeer as the district selected for the Q-methodological research is also situated in Zoetermeer and the participants can review the identified perspectives in the context of this district. The focus group lasted approximately 1 hour and 15 minutes. The researcher acted as the discussion-leader and the focus group was audiotaped with the consensus of the participants. The focus group had three participants from the municipality Zoetermeer who are all engaged in projects related to the phase-out of natural gas in the municipality. A fourth communication officer was also invited, however unfortunately she could not make it on the day itself. The participants are not mentioned by name, as they sometimes reflected on their individual experiences. The participants were:

1) the project leader education-job market, who is currently engaged in the project *Living-Lab Palenstein,* a project in which VO, MBO and HBO students collaborate and learn from each other about the phase-out of natural gas. Palenstein is the first district in Zoetermeer where natural gas will be fully phased out. The district acts as a frame-of-reference for projects, discussions and readings.

2) the programme manager sustainable and green Zoetermeer, who is in charge of the portfolio Sustainable Zoetermeer. In his role he is responsible for realizing a sustainable and green living environment in Zoetermeer. Zoetermeer has the ambition to be CO_2 neutral by 2040. Topic in this portfolio are climate and energy policy, healthy living environment and mobility, biodiversity and sustainable purchasing. Since 2016, the municipality has a special focus on gas-free districts.
3) an advisor sustainability and environment in existing build. With the Project Sustainable Zoetermeer the municipality wants to combine existing and new local initiatives for a sustainable city and give them a structural character. This advisor is in close contact with these local initiatives.

11.4.2 CONTENT

The first part of the focus group consisted of a presentation of the research and the resulting three resident-perspectives. The participants were asked to actively evaluate the perspectives and ask questions about the aspects of the perspectives that were unclear or seemed internally inconsistent. The second part of the focus group consisted of a question-guided discussion. The questions that were asked are the following:

1) What is your current communication approach with regard to the phase-out of natural gas?
2) What do you currently know about residents' needs with regard to the transition? In addition, how does this approach currently relate to these needs?
3) Can resident perspectives, like the ones presented today, support the municipality Zoetermeer in the development of a communication approach with regard to the phase-out of natural gas?
4) What is the added value of the resident perspectives as presented today?
5) How can these resident perspectives be further improved?
6) What is currently the relation between communication and decision-making with regard to the phase-out of natural gas?
7) What is currently the approach of the municipality Zoetermeer in the phase out of natural gas?
8) To what extent can insights in the residents needs with regard to this process influence this approach?

11.4.3 OUTCOME OF FOCUS GROUP

The focus group has three outcomes. The first outcome is the validation of the problem description. The second outcome regards the internal consistency and recognisability of the identified perspectives. In addition, the third outcome regards the relevance of the perspectives for the communication-and-decision-making process for gas-free districts. We will discuss these outcomes separately. Appendix 13 contains the paraphrased answers to the discussion questions.

RECOGNITION OF THE PROBLEM

The participants acknowledged the problem as presented. They understood and recognized the problems with regard to communicating about the phase-out of natural gas as identified in earlier interviews with policy officers from the municipality Leiden, Amsterdam and Rotterdam as described in chapter 1. During the presentation, especially the following definition of the problem was very recognizable: *"It is necessary to create public support for the transition to natural gas-free neighborhoods, especially given the lack of mandate of the municipality and the related dependencies of the transition on actions of individual homeowners."*

The participants also recognized the presented communication tools and methods applied in other municipalities. In addition, the participants agreed that it is difficult to select the right communication method based on the currently available information on these tools and residents expectations. The policy-officers of the municipality of Zoetermeer and their communication department are currently in the process of designing a communication approach with regard to the phase-out of natural gas. The discussion on how to design a process that fits with resident's needs and expectations towards the transition is highly relevant to them.

The participants did not recognize the trade-off between the two approaches for the development of district heating in South Holland. In this stage of the transition, the municipality of Zoetermeer focusses on all-electric solutions rather than district heating. In their view of the transition, there is no nearby district heating network, which residents in Zoetermeer can be easily connected to. The planned pipelines of the large district heating infrastructure following the approach of the PZH are (at least currently) experienced as too far from the municipality to be a viable option. Besides this, the municipality has no clear locally available heat sources, based on which a district heating infrastructure can be developed.

Internal consistency and recognisability of the perspectives

During the presentation, the participants have reflected on the three perspectives. The first two perspectives were very recognizable and understandable to them. Moreover, they make-sense and seem internally consistent. Based on their experience, the participants of the focus group recognized people in these first two perspectives. One of the respondents said about the second perspective: *"I have someone like this in my association of owners"*. The third perspective was also very recognizable. However, the perspective indicates that the resident is very strongly focussed on realizing the best option for his or her own home. However, the perspective also indicates that this person does not necessarily want to make decisions about the alternative for natural gas him or herself. He or she can also accept collective decisions that have the support of the majority of residents in his or her direct neighbourhood. This seemed internally inconsistent to the participants.

When reflecting on the qualitative interview data, this could be explained by the fact that these people highly value the process. Right processes, lead to right outcomes. The focus of the process should be individually optimal solutions and the majority should agree that these options are indeed individually optimal. The respondent wants to be able to trace and check decisions, but not necessarily perform this process his or herself. He or she has confidence in his neighbours that they are also able to perform this check. All three respondents in this perspective hint to such a process in their discussion of the statements. However, not explicitly enough to fully explain this potential inconsistency. This inconsistency can be caused by the fact that there was no data saturation. The number of interviews was too limited to cover all distinctive perspectives within the group, and the researched population. Based on this internal inconsistency, the expectation is that when more interviews are conducted, this perspective may fall apart into two or more perspectives.

Relevance of the perspectives for the communication-and-decision-making process

The policy-makers and communication experts from the municipality Zoetermeer are currently involved in developing a communication-and-decision-making process for the phase-out of natural gas in the district Palenstein in Zoetermeer. To support this process, they have recently commissioned a report on four types of lifestyles within Zoetermeer. The research indicates four different lifestyles, typed as: vitality, control, harmony and protection. This data is a nice starting point for designing communication. However, as the participants indicated, the types do not relate specifically to the phase-out of natural gas. In that sense, they provide little insight in what residents expect from the municipality in the transition.

The participants have indicated that they are very happy with the perspectives that resulted from the Q-methodological research. They found the perspectives well-structured and recognizable. They expect that the perspectives provide a good basis on which the right communication means can be selected. In addition, they expect that they can use the perspectives to check if earlier developed parts of the communication approach fit with the local expectations towards the process. This is especially relevant in the design of a process for individual homeowners. Because of the heterogeneity of this group the municipality does not know what the right time is to communicate the transition to individual home-owners, and how the municipality should present different alternatives for natural gas to them.

Content wise, the participants found it in particular interesting to see that early-communication is highly valued in all three perspectives, but also that the perspectives provide some insights in what it means to communicate "early". In addition, they found it interesting that especially the first perspective adopts a community-perspective on the transition. The municipality Zoetermeer currently focusses on individual all-electric solutions, but if this perspective is widely carried throughout districts could be a reason to put more emphasis on facilitating collective alternatives for natural gas.

The participants indicated that it would be helpful if the perspectives were complete and valid so they could start using them. Moreover, they indicated that it would be helpful if there were ways to determine which perspectives are dominant in which district, or amongst which group of residents. This is important given the scale of the transition and the relatively time-consuming nature of the research process. For example, they indicated it would be nice if the perspectives could be linked to the research mentioned earlier. Because they already know so-much about differences between these resident groups.

11.4.4 CONCLUSION

The answers to the discussion-questions show that the perspectives are very relevant for the municipality Zoetermeer. The content of the perspectives fits very well with the information need of the municipality. They cover the right topics. The content of the perspectives can therefore be used to develop or check a communication-and-decision making process design. Q-methodological research provides a means to evaluate all stereotypes and general communication advices with regard to the process of the phase-out of natural gas in a local context and to apply focus in the communication strategy.

The answers also show that the relevance of the perspectives could be further improved by extending the research to the whole of the municipality, or in particular the district they are currently phasing-out natural gas. Moreover, the municipality would like to be able to link the perspectives to data they already have bout their residents, such as socio-economic data or data on lifestyles. If the perspectives could be linked to such data, this would provide insights in what type of process should be initiated in which area, without having to perform the research for each different area separately.

11.5 CONCLUSION

In this chapter, we have answered the sub-question: *What is the relevance of identifying the perspective of residents on the process of the phase-out of natural gas for the design of governance between residents and municipalities in this transition?.* The application of Q-methodological research provides insights in the similarities and differences between multiple resident perspectives on the process of the phase-out of natural gas that can be present within a single district. With the case-study in this thesis we have shown that the application of Q-methodology provides relevant insights in the differences between resident perspectives on the phase-out of natural gas. Even with a small number of participants, and a limited validity of the outcomes, distinctive differences with regard to the problem perception, desired content of the process and desired organization of the process arise. For example with regard to the risks associated with a fast transition, the expected safety and reliability of alternatives for natural gas and the acceptance of residents towards a more directive uptake of the role of the municipality in the transition.

Moreover, the method provides guidelines for developing narratives that describe the different perspectives on the phase-out of natural gas, which are very sensitive to the respondents' subjective evaluation of the preselected topics in the Q-set. For the case study, this has resulted in three narratives describing the problem perception and desired process of the transition, from a resident perspective: 1) The municipality takes the lead, the whole society follows, 2) Individual decisions for a green, clean future, and 3) Waiting for technological progress. The largest differences between these perspectives relate to:

11) the innovativeness of the respondent and the risks associated with a fast transition (6),
12) the self-efficacy with regard to decision-making (7),
13) the problem perception and the necessity of the transition based on issues frequently associated with the transition (10),
14) the attitude towards the national transition objective and the perceived forcefulness of the transition (12) and,
15) the attitude towards the national transition objective and the distance between the government and the public in the formulation of transition objectives and organization of the transition (13).
16) the desirability of improvements to the neighbourhood when the streets are opened-up for changes to the infrastructure (22),
17) the expectations towards and desirability of independence of large energy companies (29), and
18) the expected safety and reliability of alternatives for natural gas (34).
19) the prerequisite for the transition that companies and industries also participate (40) and,
20) feelings about the way the timing of the transition should be organized (52).

This type of information can be used to overcome misconceptions process designers may have about the needs of residents in the transition process. Moreover, these insights can be used to select a local focus for the design of a communication-and-decision-making process about the phase-out of natural gas, which is sensitive to local needs with regard to the transition. This is desirable, because such a process has a better chance of realizing public support for the transition. The focus group has shown that the use of Q-methodology is of added value to the municipality Zoetermeer. This type of information is not only desirable; it is also currently unavailable for the municipality Zoetermeer.

12.

DISCUSSION AND CONCLUSION

How can municipalities gain insight in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level?

The overarching research objective is to identify the advantages and disadvantages the approach of the PBL and the approach of the PZH for realizing district heating with respect to cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050, and to determine how municipalities can develop effective decision-and-communication processes in the heat transition at a municipal level, in order to achieve public acceptance and large-scale public uptake of the phase-out of natural gas. In this third section of the thesis, we have looked into using Q-methodology to gain insights in the perspectives of residents on the process of the heat transition. In this chapter, we will briefly recap the research problem (12.1), then we will discuss the research steps and the main research results (12.2) and we will answer the main research question (12.3). Finally, we will reflect on the research (12.4) and provide recommendations for future research (12.5).

12.1 RECAP OF RESEARCH PROBLEM

The second section of this thesis mainly focussed on comparing the approach of the PBL and the approach of the PZH for developing district heating in relation to cost-effective abatement of CO2 emissions, to 85-90% of the 1990 emission levels in 2050. This resulted in an overview of the key-differences between the approaches, and a quantitative comparison of potential costs and benefits and the identification of some key uncertainties. One of the main identified uncertainties for both approaches is that of public acceptance of the transition, and the dependence of the realization of the transition objectives on the willingness and ability of individual residents to participate in the transition. In addition, recent research agendas show that there is very limited insight in how public acceptance of energy transitions can be realized (PERSON, 2016; Platform for Energy Research in the Socio-economic Nexus (PERSON), 2014). In addition, as discussed in chapter 1 orienting interviews with communication-professionals and policy-makers at three different municipalities in The Netherlands show that municipalities struggle with designing effective communication-and-decision making processes within the transition, given their own role within the transition and the process-and information needs of their residents.

Formally, for households, the largest consumer group, the decision-mandate in the transition lies with tenants and homeowners. However, stimulating private investments in residential energy systems and sustainable home improvements is traditionally difficult (Wilson & Dowlatabadi, 2007). There is a gap between technological and economic potential, and social potential, which results from the actual market behaviour (Brown et al., 1998). This social potential is difficult to predict, as individuals base their decisions on their own knowledge and assumptions about the transition. Moreover, residents can make non-decisions or emotional decisions, which influence the transition outcome (Wilson & Dowlatabadi, 2007). However, sustainable energy transitions, like the phase-out of natural gas, will be hampered without public support (Perlaviciute & Steg, 2014). It is therefore important to realize public support for the transition and to activate and enable residents to make investment-decisions that contribute to the realization of the transition.

It is currently unclear how municipalities can accomplish this public support for the heat transition. Rotmans et al. (2001) suggested that a process of collective learning and decision-making could realize public-support in energy transition. Still, they did not elaborate on this. There is therefore a need to develop a better understanding of the suggested options to create public support for this heat transition. In the literature review in chapter 8 we have complemented Rotmans et al. (2001) suggestions with the notions of Wenger (2010) and Bertone et al. (2013) that people learn through social interactions. However, that when you aim to design such a learning process, as a means to facilitate collective learning and participatory decision-making processes, should fit with the participants needs with regard to the process. This led to the following main research question:

How can municipalities gain insight in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level?

To answer this research question, we have deployed three main research steps (figure 52). Firstly, we have performed a structured literature review, to develop a theoretic framework on public acceptance of the heat transition and identify factors that may contribute to public-acceptance. Secondly, we have performed a case study to identify the residents' perspectives on a communication-and-decision-making process between residents and the municipality. Finally, we have organized a focus group, to establish the relevance of the research method and the outcomes for the municipality in designing a communication-and-decision-making process.. In 11.2 we will reflect on the selected research scope. In 11.3 we will reflect on the selected research method and we will discuss the main outcomes of each of the research steps. In 11.4 we will answer the main research question.

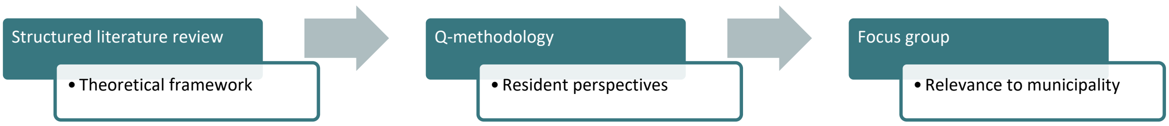


Figure 52 Main steps in research

12.2 RESEARCH APPROACH AND RESULTS

In this section, we will answer the sub-questions. We will discuss the research methods deployed. Moreover, we will discuss the research results, and we will pose three main questions that arise from the discussion of the research methods and research results. These questions can be used as input for further testing and developing the approach, as explained in 11.2. Table 49 shows the overview of the research questions, method and outcomes.

Table 48 Overview research questions, methods and outcomes

	Research question	Method	Outcome
1	How can the design of decision-and-communication processes contribute to the public acceptance of the heat transition?	Structured literature review	Conceptual model public support in the heat transition.
2	How can municipalities identify the perspectives of residents on the process of the phase-out of natural gas?	Q- methodology	Example of q-study: from discourse analysis to perspectives on the phase-out of natural gas.
3	What is the relevance of the perspectives of residents on the process of the phase-out of natural gas for designing effective communication-and-decision making processes in the heat transition?	Focus group	Insight in relevance of research approach and potential results for municipality.

12.2.1 THEORETIC FRAMEWORK

RQ2.1: How can the design of decision-and-communication processes contribute to the public acceptance of the heat transition?

DISCUSSION OF METHOD

We have started the research by performing a structured literature review on processes of collective learning and decision-making for public acceptance in energy transitions. The evaluation of research method for subjectivity in

2.2.3 has pointed out that Q-methodological research is especially suitable when revelation of the viewpoints makes a difference to the situation that is researched. In the case of the phase-out of natural gas, the viewpoints of residents on the process of the phase-out of natural gas can support municipalities in designing a process that is sensitive to the interests and attitudes of residents with regard to this transition, which can lead to public acceptance of the heat transition. Therefore, in the third section of the thesis we have applied Q-methodology to evaluate if this method can provide municipalities with relevant insights in the perspectives of residents on the process of the heat transition, to develop effective decision-and-communication processes in the heat transition at a municipal level.

We have chosen to develop a structured Q-sample, to limit the risk of excluding topics that are relevant to the resident-perspectives on the phase-out of natural gas. This required a theoretical basis that points-out what aspects of the residents' perspective on the process of the phase-out of natural gas are relevant for designing a communication-and-decision making process and therefore needed to be included in the Q-set. To develop this theoretical basis we have developed a theoretic framework about residential decision-making process design in the heat transition. To develop this theoretic framework, we have performed a structured literature review. This literature review concentrated on the following keywords:

- Decision making on residential energy systems
- Participatory decision making
- Collective learning and education for public support
- Public support for energy policy
- Social learning systems

As discussed in 8.1 the key words were selected based on the socio-technical frame that is adopted in this third part of the thesis, and the notion of Rotmans et al. (2001) that participatory decision-making and collective learning and education are two methods through which public support for energy transitions can be realized. The search engine used for the structured literature review was ScienceDirect, with a license of the TU Delft.

This structured literature review has resulted in the identification of six articles, of which only three were relevant to the study. The context of the remaining three articles deviated too strongly from the context of the research, that the articles were disregarded after reading the conclusion and introduction of the articles. The structured literature review resulted in unsatisfactory results with regard to the topic of collective learning. Therefore, the article of Wenger (2001) on Communities of Practice was added.

The number of articles found based on the search terms was very limited and did not cover all search terms. Limited licensing of the TU Delft within Science Direct or a limited coverage of relevant journals within Science Direct on this topic could cause this. In addition, it is possible that the selected search terms did not fit with the jargon used in additional relevant literature. Moreover, it is possible that the topic of collective learning and participatory decision making for public acceptance of energy transitions remains highly unexplored in scientific literature. To establish this, a broader structured literature review could be set out. This review should not limited by potential licencing, or limited by coverage of scientific databases. In addition, it should be based on a larger word-map that includes synonyms for the selected search terms. Through this additional search, the developed theoretic framework could be further improved. Alternatively, when no additional articles are found, we would have more certainty that the theoretic framework represents the existing body of knowledge on this topic.

MAIN RESULTS

For residents to take-action in residential energy transitions, like the phase-out of natural gas, self-efficacy and cognitive dissonance are important factors (Wilson & Dowlatabadi, 2007). A process of collective learning- and decision-making can influence these two factors as it can provide access to knowledge and resources and ignite cognitive dissonance, through interactions with peers and professionals. Effective processes collective learning- and decision-making in the shape of a CoP need to fit with all the design-requirements (Wenger, 2010). These design requirements depend strongly on the participants needs with regard to the process. To design an effective communication-and-decision-making process, it is therefore necessary to develop an understanding of the perspective of residents on these process-design inputs. From the literature review, we have derived the following set of needs with regard to the process design:

- Problem perception

- Organizational needs
    - Desired participants
    - Desired participant roles
    - Desired participation level
    - Desired outcome
- Content needs
    - Efficient and not wasteful
    - Protection of environment and nature
    - Security and stability
    - Autonomy and power
    - Social justice and fairness
    - Improvement and quality

DISCUSSION OF RESULTS

The discussion of the first step in the research raise additional questions with regard to designing a communication-and-decision making process for achieving public acceptance in the heat transition. Three main questions are discussed below.

WHEN IS A COP A SUITABLE STARTING POINT FOR DEVELOPING A COMMUNICATION-AND-DECISION MAKING PROCESS?

In the theoretic framework, theory on CoP is proposed as a guiding framework for designing interventions in individual learning-and-decision-making processes. However, the initiation of a CoP is a process design-choice itself. A successful CoP requires voluntary participation, individual and collective goals, mutual acceptance as learning partners, self-governance, peer-to-peer connections, personal meaning, boundary crossing, identity and interactive participation. The process-design needs relate most strongly to voluntary participation, personal meaning, boundary crossing and identity. These are requirements we can design for, based on the identified needs.

From this perspective, self-governance and peer-to-peer connections are needs rather than requirements, as they relate to the desired inclusion of participants and participant roles. Moreover, the residents' perspective on the acceptance of the municipality learning partner results from the Q-study. As such, the set of needs indicates whether a CoP can successfully support a process of collective-learning and shared decision-making or not. If the participant needs indicate that one of the requirements of effective CoP design is actually undesirable, it is necessary to look at other process design options through which collective learning and participatory decision-making can be facilitated. This lies outside the scope of this thesis project.

HOW CAN WE DEAL WITH REPRESENTATION IN COLLECTIVE LEARNING AND SHARED DECISION-MAKING PROCESSES?

The results of the Q-study show that some participants value the representation of residents in the decision-making process, however, they do not necessarily want to participate themselves. Representation can affect the anticipated effects of the collective-learning and decision-making process on the municipality, as it still facilitates that the municipality can learn from the residents about the local needs with regard to the transition:

- Learning improves process-design in terms of organization and content with regard to local needs.
- Learning improves transition policy to fit with regard to local needs.

However, it does not necessarily affect anticipated effects of the collective-learning and decision-making process on the individual resident:

- Learning shapes social norms and understanding of relative advantages.
- Activation of resources can influence self-efficacy.

It is therefore unclear how resident- representation can affect the effectiveness of a collective learning and shared-decision-making process in the realization of public acceptance for the heat transition. This requires additional research.

TO WHAT EXTEND CAN A COMMUNICATION-AND-DECISION-MAKING PROCESS INFLUENCE THE SELF-EFFICACY AND COGNITIVE DISSONANCE OF THE PARTICIPANTS?

The theoretic framework indicates that a process of collective learning and shared decision-making can influence the self-efficacy and cognitive dissonance of the participants, which would result in decision-making about the heat transition. Rotmans et al. (2001) propose the link between the process and public acceptance. In addition, the notion of Wilson and Dowlatabati (2007) that cognitive dissonance occurs when people experience a difference between their knowledge, attitudes, and actions and the notion of Wenger (2001) that we learn through our interactions with other people, provide the theoretical backing of the link. However, from the performed research, it is unclear to what extend the process of collective learning and shared decision-making actually influences the self-efficacy and cognitive dissonance of the participants. In addition, to what extend this actually leads to decision-making. A literature review or an experiment in which this relation is further deepened, could resolve this knowledge gap.

12.2.2 APPLICATION OF Q

RQ2.2: How can municipalities identify the perspectives of residents on the process of the phase-out of natural gas?

DISCUSSION OF METHOD

Secondly, we have deployed Q-methodology to identify resident perspectives on the phase-out of natural gas. We have approached this as a case study which at-least would have to generate sufficient insights in the process and outcome of Q-methodology in the context of the research, for municipalities to be able to say something about the relevance of the potential outcomes for the design of a communication-and-decision making process. Fourteen respondents evaluated and structured the statements following a prescribed procedure. The respondents (p-set) all came from a district in Zoetermeer with very common socio-economic characteristics. The respondents varied in age, home-ownership, education-level, income-level, knowledge about the transition and sustainable home improvements. Through factor analysis and factor rotation, three perspectives were identified. Moreover, the results provided detailed insights in the similarities and differences between these perspectives.

The case study had some main limitations, which are discussed in chapter 9. These limitations are limited internal validity, Limited representation of socio-economic characteristics and difficulties of respondents with regard to interpreting statement 16, 19 and 36. Because of time constraints, we did not resolve these issues. However, we have tried to mitigate the effect of the issues. The individual interpretations of the statements by the respondents have carefully been considered in the interpretation of the research results. Moreover, in the focus group the Limited validity was explicitly stated and the participants did not experience this as a limiting factor in answering the questions in the focus group.

MAIN RESULTS

Q-methodological research method can provide insights in the subjective and relative needs of residents with regard to the design of a communication-and-decision-making process. It can provide insights in the necessary focus of the decision-and-communication process both in terms of content and process design.

The application of Q-methodological research provides insights in the similarities between resident perspectives on the process of the phase-out of natural gas. The research shows that there is consensus amongst the participants on some statements that are part of the public discourse. This indicates a potential mismatch between the topics of discussion that are nationally relevant and the topics of discussion that are locally relevant. This type of information can be used to select a local focus for the communication about the phase-out of natural gas.

With the case study in this thesis, we have shown that the application of Q-methodology provides insights in the differences between resident perspectives on the phase-out of natural gas. Even with a small number of participants, and a Limited validity of the outcomes, distinctive differences with regard to the problem perception, desired content of the process and desired organization of the process arise. The largest contradictions in the evaluation of statements in the cases study are on the following statements:

1) the innovativeness of the respondent and the risks associated with a fast transition (6),
2) the self-efficacy with regard to decision-making (7),

3) the problem perception and the necessity of the transition based on issues frequently associated with the transition (10),
4) the attitude towards the national transition objective and the perceived forcefulness of the transition (12) and,
5) the attitude towards the national transition objective and the distance between the government and the public in the formulation of transition objectives and organization of the transition (13).
6) the desirability of improvements to the neighbourhood when the streets are opened-up for changes to the infrastructure (22),
7) the expectations towards and desirability of independence of large energy companies (29), and
8) the expected safety and reliability of alternatives for natural gas (34).
9) the prerequisite for the transition that companies and industries also participate (40) and,
10) feelings about the way the timing of the transition should be organized (52).

These contradictions indicate that residents have opposite needs with regard to the content and design of the process on these topics.

The method provides guidelines for developing narratives that describe the different perspectives on the phase-out of natural gas, which are very sensitive to the respondents' subjective evaluation of the preselected topics in the Q-set. For the case study, this has resulted in three narratives describing the problem perception and desired process of the transition, from a resident perspective: 1) The municipality takes the lead, the whole society follows, 2) Individual decisions for a green, clean future, and 3) Waiting for technological progress.

As the research question indicates, we are interested to see how municipalities can gain insights in the perspectives of residents on the process of the heat transition. Four main takeaways for the application of the Q-methodological research method in the context of gaining insights in resident perspective on the process of the phase-out of natural gas, that can be derived from the case study are:

1) We did not find a correlation between the described characteristics of the respondents and the identified perspectives. However, there was no data saturation. Additional research is necessary to determine whether there are correlations between perspectives and socio-economic characteristics of residents. Alternatively, additional surveys can provide insights in the distribution of a perspective throughout the population.
2) The respondents took their participation in the Q-study seriously. The respondents were satisfied with the resulting ordering of the statements and had a positive attitude towards the process. Moreover, we have seen that the respondents have experienced the participation in the study as a first step in the communication-and-decision making process that either raised awareness or triggered more questions.

Moreover, general experiences with the application of Q in the case study are:

1) It is necessary but difficult to perform a thorough evaluation of comprehensibility and unambiguity of Q-sample. Therefore, it is necessary to consider the spoken evaluation of statements in interpreting the data.
2) It is necessary but difficult to strategically select participants for the Q-study. This may result in the necessity of a larger p-sample than desired.

Discussion of results

The discussion of the second step in the research raise additional questions with regard to the use of Q-methodology to gain insights in resident perspectives on the process of the phase-out of natural gas. Five main questions are discussed below.

What is the effect of the Q-study on the participants?

The interviews with the respondents, in which they developed their Q-sorts also affected the participants. The participation in the Q-study is a first step in the communication-and-decision making process, which seemingly results in improved knowledge and a positive attitude towards the process.

1) <u>Improved knowledge</u>
   The researcher observed that the respondents took their participation in the Q-study seriously. Respondents indicated that they did some additional reading into the topic to be able to better answer the questions. Other respondents asked a lot of questions during the interview about the finances, the options and the speed of

the transition. One respondent even explicitly stated that she feels better prepared for discussions in her association of owners about the phase-out of natural gas as a result of the participation in the Q-study.

2) Positive attitude
   The respondents were satisfied with the resulting ordering of the statements and had a positive attitude towards the process. Moreover, the researcher observed that they appreciated that the results of the study would be shared with the municipality. In addition, that they positively responded to the message that the municipality was very interested in the research result.

These results are mostly based on observations of the researcher and cannot yet be sufficiently backed-up by research data. However, it fits with the notion of De Vente (2016) that tailor-made solutions result in better public acceptance of sustainability policy. This indicates that the run up to a process of collective learning and shared decision-making can also contribute to better public acceptance of the transition.

HOW PRACTICAL IS Q-METHODOLOGY TO GAIN INSIGHTS IN RESIDENT PERSPECTIVES ON THE PROCESS OF THE PHASE-OUT OF NATURAL GAS?

In the context of the practical use of Q-methodology by municipalities to identify resident perspectives on the phase-out of natural gas, we foresee the following limitations:

- Relatively large number of respondents
- Relatively long response time
- Necessity of individual personal interviews
- Necessity of a skilled researcher
- Difficulty of strategic sampling of respondents
- Sensitivity to development of perspectives over time, as a result of changing public debate

It should be questioned if these practical research limitations weigh against the benefit of the insights. Moreover, perhaps there are methods through which these limitations can be mitigated, without compromising the relevance of the results.

TO WHAT EXTEND CAN PARTICIPANTS PROJECT THE STATEMENTS REGARDING THE TRANSITION ON THEMSELVES?

Throughout the interviews, it became clear that the respondents evaluated the transition from two distinctive internal standpoints. The first standpoint relates to the national transition objective. The second standpoint relates to the personal implications of the transition. We have observed a discrepancy between the two. This was especially visible in the respondent whose mother currently lives in a district where the phase-out of natural gas will soon start. As soon as he acquired this information, his responses started to change. This raises the important question of to what extend the participants can project the transition on themselves, when the transition plans are not in the near future.

This is a very relevant question in the context of developing municipal environmental plans towards 2021. In these municipal environmental plans, municipalities should indicate what the alternative for natural gas will become, in all districts in which natural gas will be phased-out between 2021 and 2030. This means, that for the inclusion of resident perspectives on this choice-process, residents would have to think up to nine years ahead.

12.2.3 FOCUS GROUP

RQ2.3: What is the relevance of the perspectives of residents on the process of the phase-out of natural gas for designing effective communication-and-decision making processes in the heat transition?

DISCUSSION OF METHOD

To evaluate the perspectives a focus group was organized with policy-makers of the municipality Zoetermeer. The first part of the focus group consisted of a presentation of the research and the resulting three resident-perspectives. The participants were asked to actively evaluate the perspectives and ask questions about the aspects of the perspectives that were unclear or seemed internally inconsistent. The second part of the focus group consisted of a question-guided discussion. The questions can be found in section 11.4. The presentation of the research and the resulting three resident-perspectives took approximately 30 minutes; the focus-group discussion took approximately 40 minutes. The participants indicated that the perspectives seemed internally consistent and very recognisable. The participants found the perspective valuable for designing a communication and decision-making process. Moreover, the participants indicated that it would be helpful if there were ways to determine which perspectives are dominant in which district, or amongst which group of residents. Limitations this research step are 1) the absence of the communication professional amongst the participants, and 2) the current focus of the municipality of Zoetermeer on developing all-electric districts, which guided the participants thinking about the communication-and-decision-making process.

RESULTS

To fully answer the research question it is necessary to establish if the results of the Q-methodological research method can support municipalities in the design of effective decision-and-communication processes in the heat transition at a municipal level. The focus group in which we have discussed the results of the Q-study indicates that the type of information the Q-study provides is relevant for municipalities in the design of effective decision-and-communication processes in the heat transition at a municipal level. The perspectives can be used to overcome misconceptions process designers may have about the needs of residents in the transition process. Moreover, these insights can be used to select a local focus for the design of a communication-and-decision-making process about the phase-out of natural gas, which is sensitive to local needs with regard to the transition. This is desirable, because such a process has a better chance of realizing public support for the transition. The focus group has shown that the use of Q-methodology is of added value to the municipality Zoetermeer. This type of information is not only desirable; it is also currently unavailable for the municipality Zoetermeer.

In conclusion, Q-methodological research for identifying resident perspectives on the phase-out of natural gas, based on a theoretic framework for collective learning and decision-making for public acceptance in energy transitions provides valuable insights in how to design effective communication-and-decision-making processes. The perspectives provide a starting point for developing an approach for communication-and-decision making that be tailored to the residents needs in this transition. As this is a prerequisite for successful shared learning and decision-making processes, these perspectives can contribute to realizing public support for the heat transition.

DISCUSSION OF RESULTS

The discussion of the third step in the research raise additional questions with regard to the role of the municipality in designing communication-and-decision-making processes in the context of the heat transition. Three main questions are discussed below.

HOW DOES THE PERSPECTIVE OF MUNICIPALITIES ON THE COMMUNICATION-AND-DECISION-MAKING PROCESS AFFECT THE PROPOSED METHOD?

During the focus group, it became clear that the municipality Zoetermeer currently focusses on developing all-electric concepts for the phase-out of natural gas. While the municipality is clearly stated in the plans of the Province of South Holland, to be prospective location for the main heat infrastructure, the policy-makers at the municipality did not experience district heating as a near-future alternative for natural gas. This shaped their way of thinking about the communication-and-decision-making process. Their thinking mainly circled around homeowners who needed to be supported in the individual decision-making process. The perspective of the municipality on the communication-and-decision-making process will shape what they find important with regard to resident perspectives on this process. It may therefore be necessary that an external researcher, rather than an internal policy-maker, performs the Q-study. Furthermore, to identify the differences between the resident perspectives on the communication-and-decision-making process and the municipal perspective on the communication-and-decision-making process, it could be useful that municipal policy-makers also engage in the Q-study as participants.

HOW DO THE AVAILABLE ALTERNATIVES FOR NATURAL GAS SHAPE THE EFFECTIVENESS OF THE COMMUNICATION-AND-DECISION-MAKING PROCESS?

In relation to the previous question, sometimes the decision-space for alternatives for natural gas is constrained by financial or technical constraints. The residents' view of the transition and the residents' needs with regard to the process design, may not coincide with the actual decision-problem at hand. The current research provides only very Limited insights in how this affects the effectiveness of the design of a communication-and-decision-making process. When the design does not fit with the residents needs with regard to the process, the process is likely to fail.

TO WHAT EXTEND CAN THE MUNICIPALITY SATISFY THE DIFFERENT PERSPECTIVES WITHIN A PROCESS-DESIGN?

The theoretical framework developed in chapter 8 indicates that it is necessary that a process of collective learning and shared decision-making can only be effective in realizing public support, when the content and organization of the process match with the needs of the participants. The identified differences in problem perception and needs with regard to the content and organization of the process indicate that there may not be a "one size fits all" solution for a process design within a single neighbourhood. The organization of the process and the emphasis of the content of the process needs to be tailored to fit these differences.

12.3 CONCLUSION

How can municipalities gain insight in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level?

The main conclusion of this part of the thesis is, that Q-methodology can be a suitable method for gaining insights in resident perspectives on the phase-out of natural gas. Through applying a Q-study, municipalities can gain insights in the relative importance of aspects of the decision-making process that seem relevant based on literature or based on public discourse. The insights tell the municipality something about: 1) how different groups of residents view the transition, 2) what aspects of the transition they find important in the decision-making process and 3) what process-design choices fit with the local needs. The insights municipalities can gain from a Q-study are both relevant and unique. Municipalities can use Q-methodology to learn about the needs of their residents in a collective learning-and-decision-making process, both in terms of process design, and knowledge development.

Moreover, we have only evaluated the use of a Q-study for gaining insights in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level. While as discussed in 11.2 Q-methodological research fits very well with the socio-technical theoretical frame we have adopted and the corresponding insights in public acceptance of energy transitions. This means that there are potentially other methods that can provide relevant insights.

12.4 REFLECTION

In this section we will reflect on the scoping decisions, the selection of a case-study and the general research process.

12.4.1 RESEARCH SCOPE

In this section, we will discuss the choices we have made in scoping the research. The research approach should allow us to achieve the goal of the research. The aim of the research is to determine how municipalities can develop effective decision-and-communication processes in the heat transition at a municipal level, in order to achieve public acceptance and large-scale public uptake of the phase-out of natural gas. As discussed in chapter 2, the research is scoped to develop an understanding of how municipalities can design a process of shared-decision-making and collective learning and education. We have made three main scoping decisions in the research approach:

1) We looked at the heat transition from a socio-technical perspective. This perspective fits with the legal position of residents in the heat transition and allows us to look at decisions from an institutional perspective, which fosters human behaviour. From this perspective, shared decision-making and collective learning can contribute to public acceptance of the transition.
2) We have developed an understanding of such processes based on the concept of a CoP. This is a term to describe the building blocks of our social learning systems. Social learning occurs through interactions and experiences. A CoP can emerge or be designed. From an instrumental perspective, it is an approach for organizing shared decision-making and collective learning and education processes.
3) We have applied Q-methodological research to establish if this can provide relevant insights in the needs of residents with regard to communication-and-decision-making processes, which are prerequisites for a successful community of practice.

These scoping choices have limited the extent to which we are able to fulfil the research goal. We have developed and tested a single method through which municipalities can develop a decision-and-communication processes in the heat transition that would theoretically contribute to improving the public acceptance of the heat transition. However, as the scoping choices indicate, there are potentially many more methods through which public acceptance of the heat transition could be realized or improved. As such, we have not answered the research question to its full extend.

12.4.2 THEORETIC FRAMEWORK

Moreover, as highlighted in the discussion of the theoretic framework in 11.2, we have used a relatively small sample of words to perform a structured literature review. Additionally, we have only used a single search engine. The theoretic framework could be further improved by extending the structured literature review based on associated search terms. Moreover, when this does not provide satisfactory results, a snowball search can be performed to develop a better understanding of the relevant terminology and theories associated with public acceptance of energy transitions.

12.4.3 CASE-STUDY

We have chosen to perform a case study. This case-study took place in Seghwaert, Zoetermeer. We have attempted to perform a strategic selection of the participants, to limit the number of interviews that are necessary to establish a full set of perspectives. However, strategic sampling proved to be difficult. Mainly relatively high educated, individual homeowners in the age of 45-60 were willing to participate in the study. Moreover, most participants were found through a reference of another participant. This means that the variety of the participants was limited. Not only in the socio-economic characteristics, but potentially also though other factors that shape the social circle.

Through this case-study, we have established that the civil servants that are currently working at the municipality of Zoetermeer on the phase-out of natural gas find the outcomes of the Q-study relevant and beneficial for developing a communication-and-decision-making process. When we look at figure 53, which shows the total of steps necessary to evaluate the proposed method, we have only performed step one, two and three. To further confirm the relevance and effectiveness of using Q-methodological research as method to collect inputs for designing effective processes of collective learning and shared decision-making, we should continue with steps four to seven, in which we make the step from an initial proof-of-concept, to actually performing and testing the method in a real-life setting.

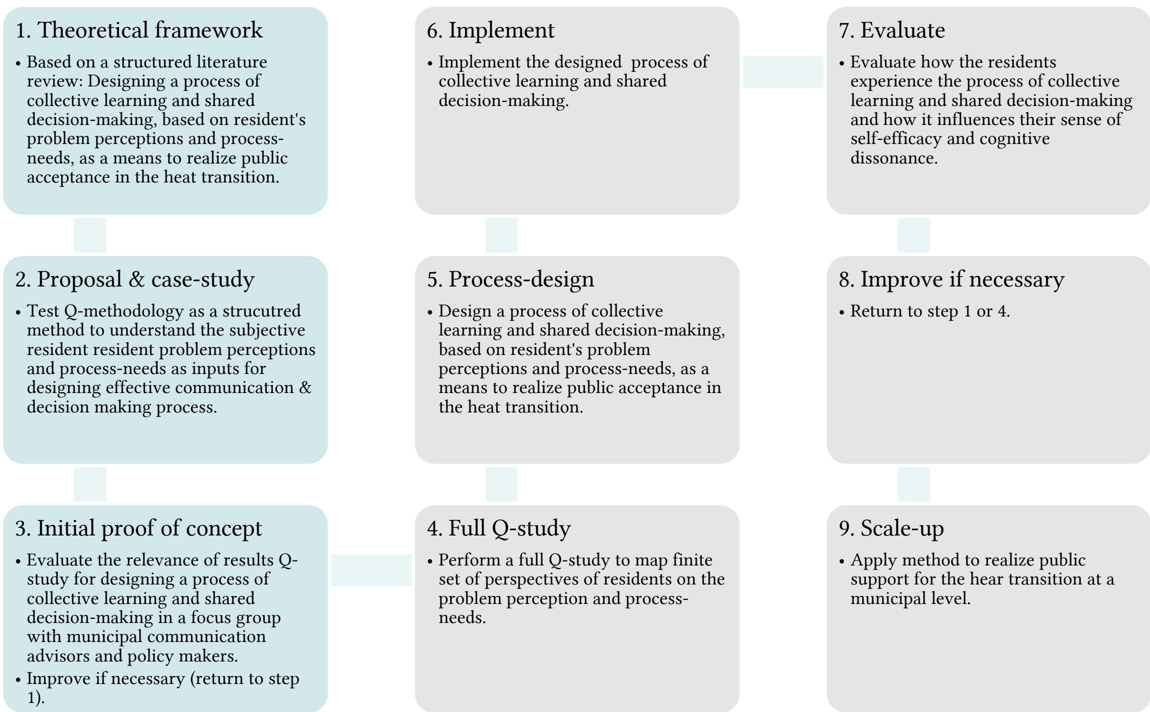


Figure 53 Current and future steps in research

At this moment, a process to continue testing and developing this approach (step 4 to 8) is initiated in a collaboration between HVC, a company that exploits and develops district heating infrastructure, and HIER Klimaatbureau, a leading organization in the communication about the phase-out of natural gas. Both parties have committed workforce and/or finances to further explore this method.

12.5 RECOMMENDATIONS FOR FUTURE RESEARCH

The discussion of the research results in section 12.2 shows that there are still many practical and conceptual questions related to applying Q-methodology to gain insights in the perspectives of residents on the process of the heat transition to develop effective decision-and-communication processes in the heat transition at a municipal level. These questions relate to:

- the position of a CoP as a theory or a process design choice in the context of the theoretical framework,
- the effect of representation on the anticipated benefits of collective-learning and shared decision making,
- the actual effect of a process of collective-learning and shared decision making on cognitive dissonance, self-efficacy and decision-making,
- the effect of participation in a Q-study on public acceptance,
- the relative advantages of the insights with regard to the practical efforts of performing a Q-study,
- the extent to which participants can project the statements on themselves when the actual transition is not yet perceived as current, and the effect of this on the research outcome,
- the effect of the subjective perspective of the municipality on the transition, on the design and interpretation of the Q-study,
- the effect of a locally constrained decision-space (technical, financial) on the perspectives of residents on the transition process, and
- the practical implications of designing a local process of communication-and-decision making that fits with different (contradicting) perspectives on this process.

In the process to continue testing and developing this approach, based on a collaboration between HVC, a company that exploits and develops district heating infrastructure, and HIER Klimaatbureau, a leading organization in the communication about the phase-out of natural gas, these should be topics of attention.

SECTION 4 INTEGRATION AND FINAL RECOMMENDATIONS

13.

INTEGRATION AND FINAL RECOMMENDATIONS

In this section, we will integrate the outcome of the two parts of the thesis. Based on this integration we will propose adjustments to the current processes municipalities are advised to follow in selecting alternative heat technologies for natural gas and preparing environmental plans.

UNCERTAINTY

We currently observe that municipal transition policy is based on top-down knowledge development. Municipalities look at the PBL and/or at the PZH to understand how the development of district heating will take place. Based on this frame of reference, municipalities develop an understanding what type of information they need to execute the transition successfully. They develop probability maps for district heating (facilitated by CE Delft, the PBL and OverMorgen) and engage in negotiations with either local companies that have residual heat, or the Heat Alliance to make plans for developing district heating in areas where this seems to be the best option. The execution of these plans however does not fit with the mandate of the municipality. This may result in a gap between the expectations of the municipality with regard to the development of district heating based on the technical and financial feasibility of the plans, and the actual development of district heating which includes the social feasibility of the plans.

Moreover, these probability maps suffer from (most of) the limitations we have discussed in relation to the Vesta/MAIS model; they are not transparent about their assumptions, they do not provide insights in the uncertainty margins and they lack relevant aspects in the transition process with regard to the decision-mandate of residents. To make matters even more complex, these probability maps also sometimes result in contradicting advices (Discussion energy transition models, policy makers PZH and PWKZH, 17-05) as they deploy different sets of criteria for evaluating the technical and financial feasibility of district heating systems.

Given the analysis we have performed in this thesis we should re-evaluate the current position of heat atlases in the policy process. The models that underlie these atlases are a simplified representation of reality. Moreover, the models that simulate district heating network development suffer from so many degrees of freedom that this is a non-linear and non-unique optimization problem. Policy makers should accept that the heat transition is too complex to be fully captured in model-based predictions. Instead, they should become attentive towards understanding the assumptions and the uncertainties that underlie the model results they are faced with, and interpret them in light of the local and regional or national transition objectives.

We have suggested to removing all model heuristics that determine the potential for district heating based on network growth and instead, communicating relevant trade-offs between the alternatives, including but not limited to cost-estimates, and uncertainty margins for each technology per neighbourhood. After which for district heating technical feasibility can be assessed and where relevant a trade-off can be made be between dimensioning to current local demand, and thus controlling investment risk, but also potentially impeding (cost-effective) network growth, or dimensioning to future expected demand, and accepting the risks of over-dimensioning. An important aspect of this advice is the notion of "*relevant trade-offs*".

We have seen that an important knowledge gap is the development of the heat demand and the share of heat consumers that are willing to connect to district heating. There is limited insight in how the total heat demand will develop over time because of construction, demolition, insulation, demographic development etc. However, more importantly, there is no insight in the share of residents that is actually willing and able to transition to district heating.

SOCIAL FEASIBILITY OF TRANSITION PLANS

In the third section of the thesis, we have therefore researched how municipalities can gather information about the subjective decision-criteria of residents. When municipalities develop a better understanding of when residents are willing and able to transition to district heating, they can reduce the knowledge gap on the demand-side of the development of district heating infrastructure. Moreover, they are potentially better able to evaluate the complex trade-offs between the two transition approaches in the local context.

In the third part of the thesis is we have evaluated if Q-methodology can provide relevant insights in the needs of residents in the transition. Moreover, we have evaluated if Q-methodology can provide relevant insights in how municipalities can design communication-and-decision-making processes that fit with the residents needs towards the transition, and as such effectively support learning-and-decision-making processes. We have concluded that Q-methodology can be a suitable method for gaining insights in resident perspectives on the phase-out of natural gas. Through applying a Q-study, municipalities can gain insights in the relative importance of aspects of the decision-making process that seem relevant based on literature or based on public discourse. The insights tell the municipality something about: 1) how different groups of residents view the transition, 2) what aspects of the transition they find important in the decision-making process and 3) what process-design choices fit with the local needs. The insights municipalities can gain from a Q-study are both relevant and unique. Municipalities can use Q-methodology to learn about the needs of their residents in a collective learning-and-decision-making process, both in terms of process design, and knowledge development.

In the literature review and case study, we have seen that residents adopt a wider set of decision-criteria for energy transitions than is currently reflected in the policy goal. Where the policy goal entails: cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050. The set of values residents deploy in evaluating the heat transition includes:

- Efficient and not wasteful – efficient use of energy and minimizing waste
- Protection of environment and nature – environmentally conscious
- Security and stability – safe, reliable and accessible
- Autonomy and power – both at national and personal levels
- Social justice and fairness – open, transparent fair, and attentive to the effect of peoples’ lives
- Improvement and quality – improvements of quality of life

So far, we have predominantly highlighted the learning-and-decision-making processes of residents. However, when we reflect on the transition goal and the set of values residents deploy in evaluating the heat transition, we see that these communication-and-decision-making processes can be of great value for municipalities, and regional governments such as the Province, to guide their own learning processes. Existing learning approaches, let it be modelling or process-driven knowledge development, are not tentative to these values.

CHANGING THE POLICY PROCESS

The application of Q-methodology, allows us to reverse the thought processes about what type of information municipalities need to formulate environmental plans for the heat transition. Rather than answering the question: What is the optimal choice for district heating in this area, based on technical and financial constraints? We should be asking: What information does the resident need to make well-informed decisions in the heat transition? Answering this question results in a demand-driven process of knowledge development, which is more tentative to values residents may find important, like: efficient and not wasteful, protection of environment and nature, security and stability, autonomy and power, social justice and fairness and improvement and quality of life. This means that current processes of knowledge development need to be improved based on the local information needs.

As a result, the risks in the policy process shifts. Where knowledge development initially focussed on realizing the policy target of cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050, at a risk of societal resistance resulting in an incomplete phase-out of natural gas. It now focuses on limiting the societal resistance of the heat transition and realizing a full phase-out, while potentially mitigating the extent to which we are able to realize cost-effective abatement of CO_2 emissions, to 85-90% of the 1990 emission levels in 2050.

SCALE OF RESPONSE

Placing the two approaches in the transition context shows how difficult it is to formulate a transition approach at municipal level. Individual municipalities do not have the individual power to change the (local) energy-market and policy conditions and they lack the mandate to enforce the transition otherwise. So to realize a full transition, they are either dependent on national policy or external influences that change the market conditions. Moreover, they are highly dependent on the willingness and ability of residents to participate in the transition. It should therefore be questioned if municipalities have the right scale of response to the scale of the problem.

This is a clear example of a phenomenon described by Adger et al (2005), Abbot (2012) and Muinzer & Ellis (2017) . Climate change policy is distributed among different levels of policymaking and execution (international, intra-national, national and sub-national) and types of organizations (state, firm and civil society organizations). While decentralized climate change policy has the ability to fine-tune governance to specific contexts, and adapt to changing conditions (Abbott, 2014). A level of coordination remains necessary: firstly to ensure rapid responses to higher-level policy goals; and, secondly because fragmentation can impede learning (Abbott, 2014). In addition to this, Adger et al. (2005) say that the effects of climate change policy should be evaluated among different scales of effect, because these levels are interdependent. This shows for example in the trade-off between optimizing towards cost-effective CO_2 abatement (the approach of the PBL), or optimizing towards total CO_2 abatement (the approach of the PZH).

In chapter 6, we have seen that when local transition policy is solely focused on the cost-effectiveness of transition measures, the related goal of abatement of CO_2 emissions to 85-90% of the 1990 emission levels in 2050 may not be achieved. This is especially relevant when we adapt the policy process to fit with other values residents find important in the choice for an alternative for natural gas. The more we fine-tune the decision to local needs with regard to the transition, the more we may deviate from the initial transition objective. However, to realize the transition, the municipality either needs to be either sensitive to these needs, or the municipality needs to have the mandate to decide otherwise.

APPENDIX

APPENDIX 1: MODEL SETTINGS AND INPUTS VESTA/MAIS

This appendix shows the model settings and main data inputs of the Vesta/MAIS model as they were used for the analysis of the approach of the PBL in this thesis.

A.1.1 PRICE DEVELOPMENT IN THE VESTA/MAIS MODEL

The table below shows the used energy prices [€/MWh] incl. transport and distribution costs, SDE-surcharge and energy tax.

Table 49 Energy and CO_2 prices 2030

Product	
Natural gas	€ 31,20*
Coal	€ 8,67
Biomass	€ 19,97
Green gas	€ 31,20**
Electricity	€ 124,00
Heat	€81,78 ***
	Price [€/ton]
CO_2	€ 37,00

* based on the electricity price for large consumers (>10 billion kWh/year) in Vesta
** based on the gas price for large consumers (>1 billion m3/year) in Vesta
*** Dutch regulated heat price, 2017

The table hereafter shows the assumed CO_2 emissions per fuel type.

Table 50 CO_2 emissions per fuel: adopted from Vesta

Product	Emissions [ton/MWh]
Natural gas	0.061
Coal	0.39
Biomass	0.39
Green gas	0.061
Electricity	0.061

The next figure shows the development of heat production costs in the Vesta/MAIS model.

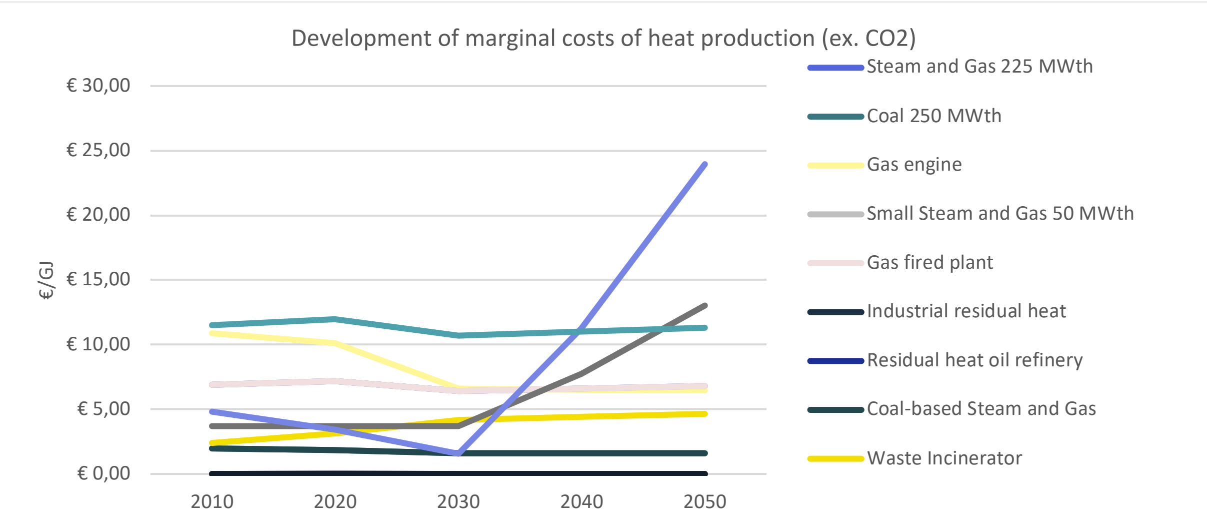


Figure 54 Development of marginal costs of heat production (Vesta) excluding costs for CO_2 emissions

A.1.2 KEY SETTINGS FOR HEAT IN THE VESTA/MAIS MODEL

This section describes some key policy options and settings in the Vesta/MAIS model for the development of district heating. For this study, the shown default values were used.

A.1.2.1 SUBSIDIES HEAT PROJECTS

The following subsidy settings were used for investment in and operation of district heating systems.

Table 51 Subsidies district heating systems

Code	Default value	Description
R_SplitIncentiveFactor	0.8	Fractie die aangeeft welk gedeelte van de vermeden kosten bij energiebesparing terecht komt bij de eigenaar (0,8 houdt in dat 80% van de opbrengsten terecht komt bij de eigenaar). Hierbij wordt geen rekening houden met het rebound effect, er wordt dus uitgegaan van de theoretische besparing.
S_LokaleOpwekking	0	Investeringssubsidie op de lokale opwekking bij gebouwen, subsidie als fractie van de investeringskosten
S_GebouwVerbetering	0	Investeringssubsidie op gebouwverbetering (schil), subsidie als fractie van de investeringskosten
S_Ongeriefsvergoeding	0	Subsidie op ongeriefsvergoeding, subsidie als fractie van de eenmalige kosten
S_Projectmanagement	0	Subsidie op projectmanagement, subsidie als fractie van de eenmalige kosten
id	0	Investeringssubsidie op de inpandige distributie (id), subsidie als fractie van de investeringskosten
wd	0	Investeringssubsidie op de wijkdistributie (wd), subsidie als fractie van de investeringskosten
pt	0	Investeringssubsidie op primair transport(pt), subsidie als fractie van de investeringskosten
WKO	0	Investeringssubsidie op WKO, subsidie als fractie van de investeringskosten
ow	0	Investeringssubsidie op andere opwekkers (ow), subsidie als fractie van de investeringskosten

A.1.2.2 SUBSIDY HEAT PRODUCTION

The following subsidy was used for heat production.

Table 52 SDE subsidy for heat

Code	Default value	
SDE	0	Subside per geleverde hoeveelheid warmte (Euro/GJ) voor de opwekker (exclusief WKO)

A.1.2.3 HEAT PRICE

The following logic was used for the establishment of the heat price.

Table 53 Heat price

Code	Default value	Description
MinderDanAndersFactor	1	Fractie van de aardgasprijs die betaald moet worden aan warmte van de warmtenetten.

A.1.2.4 HEAT LAW

The following values were used for the calculation of the maximum prices for heat and heat connections.

Table 54 Data maximum price calculation

Code	Default value		Description
CPI_2013_08_31	115.39	%	Consumer Price Index van 31 augustus 2013
CPI_2010	106.72	%	Consumer Price Index van 2010
Maximum2014	753.53	Euro/connection	Prijs van de aansluitbijdrage gebruikt voor NMDA
Maximum2016	795.83	Euro/connection	Prijs van de aansluitbijdrage gebruikt voor NMDA
Maximum2014	209.92	Euro/year/connection	Prijs van vastrecht
Maximum2016	228.21	Euro/year/connection	Prijs van vastrecht

A.1.3 AVAILABLE HEAT IN VESTA/MAIS

The table below shows the list of available and potential heat sources in the Vesta/MAIS model in South Holland, divided over the clusters.

Table 55 List of potential and current heat sources in Vesta/MAIS

Name	Type	Capacity (MWth)	Cluster
Dordrecht	Waste incinerator	113	Dordrecht
Rotterdam	Waste incinerator	126	Rotterdam South
Rozenburg	Waste incinerator	387	Botlek
Boterdorp	Gas engine	5	Lansingerland
OosterHeem	Gas engine	5	Lansingerland
Oostpolder	Gas engine	5	Rotterdam South
Rijtuigweg	Gas engine	5	Lansingerland
Vaanpark	Gas engine	5	Rotterdam South
Wateringseveld	Gas engine	5	The Hague
WKC Ypenburg	Gas engine	10	The Hague
BP	Oil refinery	125	Botlek
Esso	Oil refinery	125	Botlek
Koch	Oil refinery	125	Botlek
Kuwait	Oil refinery	125	Europort
Shell	Oil refinery	125	Botlek
EON-MPP-3	Coal fired plant	698	Europort
GDF Suez NL-Maasvlakte	Coal fired plant	480	Europort
Den Haag-15	Gas fired plant	76	The Hague
Enecogen-2 Dong	Gas fired plant	219	Europort
Leiden-12	Gas fired plant	83	Leiden
Maasstroom Energie	Gas fired plant	247	Botlek
Rijnmond Energie-1	Gas fired plant	235	Botlek
Rijnmond Energie-2	Gas fired plant	235	Botlek
Roca-1	Gas fired plant	70	Rotterdam North
Roca-2	Gas fired plant	70	Rotterdam North
Roca-3	Gas fired plant	200	Rotterdam North

A.1.4 HEAT DEMAND IN VESTA/MAIS IN 2030

The following table shows the heat demand in 2030 of the Vesta/MAIS model in South Holland given the standard model settings, divided over the clusters.

Table 56 Heat demand in Vesta/MAIS in 2030 under standard model settings

Municipality	SUM (MW)	Households (MW)	Utility (MW)	Greenhouse (MW)
Alblasserdam	11,6	9,3	2,3	0,0
Alphen aan den Rijn	79,9	53,9	14,9	11,1
Barendrecht	32,0	22,2	6,2	3,5
Bergambacht	6,5	5,5	1,0	0,0
Brielle	42,4	9,6	2,5	30,4
Capelle aan den IJssel	39,1	28,7	10,4	0,0
Delft	80,0	47,0	32,9	0,1
Dordrecht	80,7	59,0	21,8	0,0
Gorinchem	27,7	17,1	10,6	0,0
Gouda	52,8	37,6	15,1	0,1
's-Gravenhage	348,1	231,8	116,3	0,0
Hardinxveld-Giessendam	12,0	8,9	3,2	0,0
Hellevoetsluis	23,1	18,7	3,9	0,6
Hendrik-Ido-Ambacht	21,8	14,8	2,3	4,7
Hillegom	15,0	10,5	2,9	1,6
Katwijk	56,8	27,8	8,2	20,7
Krimpen aan den IJssel	16,9	13,5	3,4	0,0
Leerdam	13,5	10,4	3,1	0,0
Leiden	85,4	55,9	29,2	0,2
Leiderdorp	18,3	12,2	6,1	0,0
Lisse	16,4	10,8	4,8	0,8
Maassluis	20,1	15,8	3,7	0,7
Bernisse	8,8	8,0	0,8	0,0
Nieuwkoop	48,0	14,4	3,7	29,9
Noordwijk	21,6	13,7	5,7	2,2
Noordwijkerhout	16,1	8,3	2,7	5,1
Oegstgeest	15,4	11,8	2,5	1,2
Oud-Beijerland	16,3	11,4	3,5	1,4
Binnenmaas	26,8	16,5	2,3	8,0
Korendijk	7,4	6,6	0,7	0,2
Papendrecht	18,7	15,3	3,3	0,0
Ridderkerk	43,0	22,0	7,4	13,6
Rotterdam	433,6	271,7	140,0	21,9
Rijswijk	52,1	22,8	21,8	7,5
Schiedam	49,6	36,2	13,4	0,0
Schoonhoven	8,2	6,3	1,9	0,0
Sliedrecht	17,3	12,4	5,0	0,0
Cromstrijen	9,7	7,3	0,9	1,5
Spijkenisse	42,3	34,8	7,4	0,0
Albrandswaard	18,6	13,2	2,8	2,6
Westvoorne	44,6	9,6	1,9	33,1
Strijen	9,8	5,4	0,6	3,9
Vlaardingen	41,4	31,5	9,9	0,0
Vlist	7,5	5,3	1,1	1,0
Voorschoten	17,9	13,6	3,2	1,1
Waddinxveen	33,4	13,6	4,3	15,5
Wassenaar	20,1	14,6	4,7	0,7
Zoetermeer	75,2	57,3	17,9	0,0
Zoeterwoude	7,3	4,3	2,0	1,0
Zwijndrecht	28,2	20,5	5,5	2,2
Nederlek	10,7	9,4	1,3	0,0
Ouderkerk	4,7	4,2	0,5	0,0
Giessenlanden	10,2	8,3	1,8	0,1
Zederik	9,4	7,8	1,6	0,0
Teylingen	30,1	21,5	5,7	2,9
Lansingerland	280,3	34,4	6,9	239,0
Westland	750,8	52,1	15,2	683,6
Midden-Delfland	85,8	9,3	2,3	74,2
Kaag en Braassem	17,1	14,2	2,9	0,0

Zuidplas	81,2	19,5	5,2	56,5
Bodegraven-Reeuwijk	24,1	18,1	4,8	1,2
Leidschendam-Voorburg	56,1	34,3	11,5	10,3
Goeree-Overflakkee	44,0	26,9	10,3	6,8
Pijnacker-Nootdorp	129,1	27,3	4,8	97,0
Molenwaard	18,8	15,1	3,6	0,1

A.1.5 WLO SCENARIO

The model was run under the WLO low scenario. The WLO scenarios describe economic and demographic developments. In the Vesta/MAIS model, these scenarios are translated into the price scenarios for electricity, natural gas, coal, biomass and CO_2. These forecasts can be found in the Vesta model at:

- D:\Vesta\PD\VestaDV-master_v2\data\ 20160528_Vesta_energieprijzen_WLO_hoog.xls
- D:\Vesta\PD\VestaDV-master_v2\data\ 20160528_Vesta_energieprijzen_WLO_laag.xls

APPENDIX 2: SENSITIVITY ANALYSIS VESTA/MAIS

In this appendix, the performed sensitivity analysis of the Vesta/MAIS model for the analysis of the PBL approach is described. In collaboration with the PBL factors for a limited sensitivity analysis were selected to validate if the district heating system design gives a stable outcome of the Vesta/MAIS model. The Vesta/MAIS model is a deterministic model. Therefore, it is necessary to only include multiple system designs in the analysis from a national perspective for the sensitive parameters.

The sensitivity analysis of the Vesta/MAIS model was limited to the following three inputs:

1. WLO scenarios
2. CO_2 price
3. Investment costs heat transport infrastructure

A.2.1 WLO SCENARIOS

The development of the demand within Vesta/MAIS depends on the input data and settings of the model. The Vesta/MAIS settings include the choice for a scenario of the economic and demographic development in the Netherlands. These scenarios were developed by PBL. The first WLO scenario is that of high economic and demographic development. The second WLO scenario describes low economic and demographic development. Both developments are depicted below.

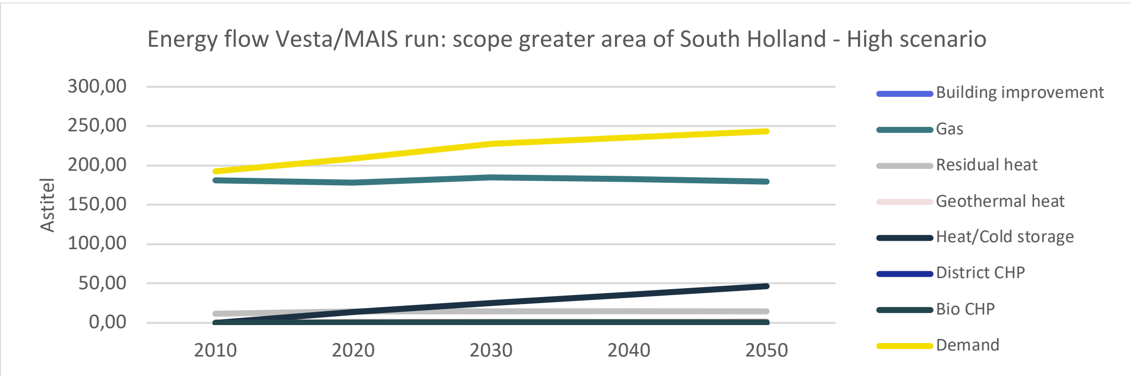


Figure 55 The energy flow outcome of the Vesta/MAIS model for the WLO high scenario

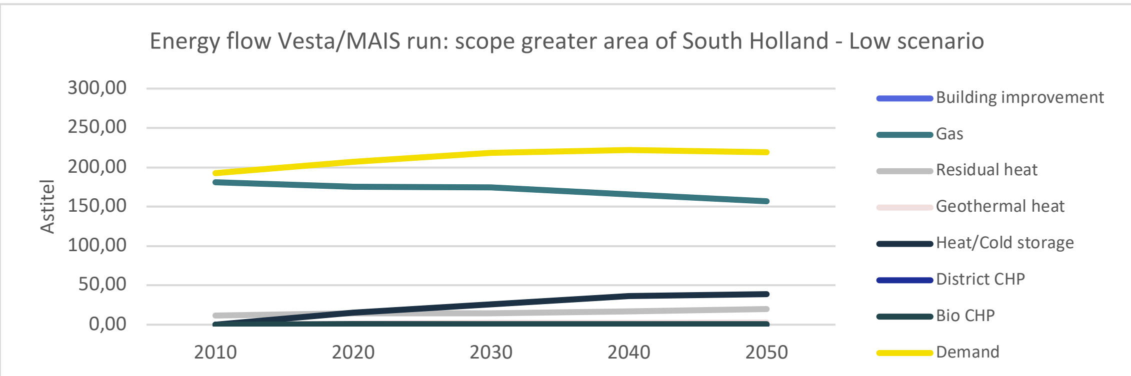


Figure 56 The energy flow outcome of the Vesta/MAIS for the WLO low scenario

The latter two figures show that the two scenarios result in the following differences and similarities with regard to heat supply and demand:

1) In the WLO low scenario, the total demand for energy is about 50 PJ smaller in 2050 than in the high scenario. This is the result of a smaller population, slower economic development and high energy prices.
2) In the WLO low scenario, the supply of gas decreases while the supply of gas remains approximately stable in the high scenario.
3) The supply of heat/cold via a heat/cold storage system is approximately the same in both WLO scenarios.
4) The supply of heat via a district heating network is approximately the same in both WLO scenarios.
5) In both WLO scenarios, there are no investments in building improvements, i.e., the energy demand per building remains the same throughout the model run.

By default, the model uses the WLO high scenario; therefore, in this study, the WLO high scenario was used.

The development of the total energy demand is sensitive to the WLO scenario. However, the development of the energy demand connected to district heating infrastructure and the development of district heating systems based on geothermal heat are not. Therefore, it is not necessary to incorporate demographic and economic development in the scenario development for district heating in the approach of the PBL.

A.2.2 CO_2 PRICE

To test the sensitivity of the development of district heating and the development of the total heat demand for the CO_2 price, the Vesta/MAIS model was run for six different constant CO_2 prices. The reported values are the values from the year 2030 in the model outcome. The model assumes a standard CO_2 price of €15 per ton in 2010, growing to €37 per ton in 2030 (see table below).

Table 57 Development of district heating in 2030 given the CO_2 price

RUN	0	1	2	3	4	5
CO2 Price (€/ton)	37	10	50	100	150	300
Natural gas	89%	93%	89%	86%	83%	49%
District heating	10%	7%	9%	13%	16%	50%
Geothermal heat	1%	1%	2%	2%	2%	37%
Residual heat	9%	5%	9%	11%	14%	13%
Bio-based CHPs	0%	1%	0%	0%	0%	0%
Total demand	120	116	115	112	108	100

The development of district heating networks is not sensitive for the CO_2 price. Nor is the development of district heating networks based on geothermal heat sources or the total heat demand. Only when the CO_2 price is increased to €300 per ton emissions, the development of district heating networks based on geothermal heat sources increases significantly. Moreover, the total heat demand is not sensitive to the CO_2 price.

A.2.3 INVESTMENT COSTS HEAT TRANSPORT INFRASTRUCTURE

To test the sensitivity of the development of district heating and the development of the total heat demand for the investment costs of the district heating transport infrastructure, the Vesta/MAIS model was run for six different constant subsidy levels for the district heating transport infrastructure. The reported values are the values from the year 2030 in the model outcome (see following table).

Table 58 Development of district heating given % subsidy transport infrastructure in 2030

RUN	0	1	2	3	4	5
% subsidy	0%	10%	25%	50%	75%	100%
Natural gas	89%	89%	89%	89%	88%	87%
District heating	10%	10%	10%	11%	11%	13%
Geothermal heat	1%	1%	1%	1%	1%	1%
Residual heat	9%	9%	9%	10%	10%	12%
Bio-based CHPs	0%	0%	0%	0%	0%	0%
Total demand (PJ)	120	116	116	116	116	116

The total energy demand, the development of district heating networks and the development of district heating networks based on geothermal heat are not sensitive for the investment costs of the primary heat transport infrastructure.

APPENDIX 3: VERIFICATION AND SENSITIVITY ANALYSIS OF THE MODEL INVESTMENT COSTS

This appendix contains a report on the model verification steps taken for the cost-model and the sensitivity analysis of the costs model.

A.3.1 VERIFICATION

The figure below shows the composition of the investment costs for a system that can supply 50 PJ annually.

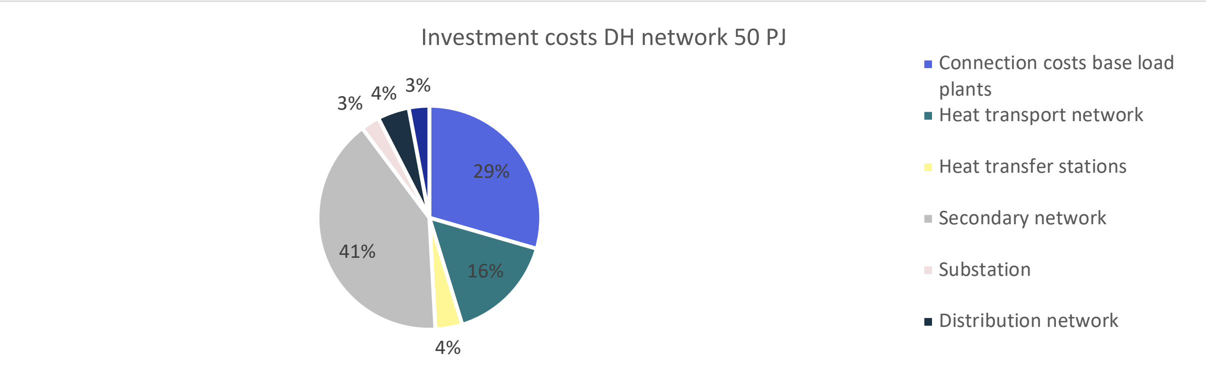


Figure 57 Investment costs of a district heating system with 50PJ supply annually

The figure hereafter shows the change in the investment costs for various values of the heat demand. The primary heat infrastructure and the capacity of the heat sources are dimensioned on a district heating network of 50 PJ.

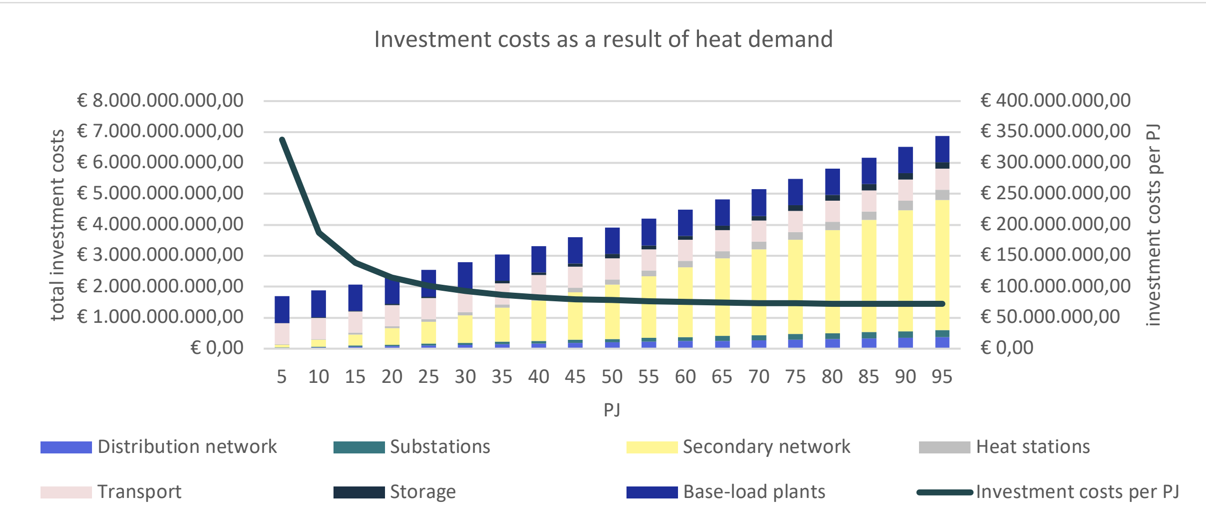


Figure 58 Investment costs as a result of the heat demand

The latter figure shows that for a decreasing demand, the investment costs per PJ rapidly increase. This can be explained by the fact that the investment costs in the primary heat infrastructure and connected heat sources are not scaled to the demand by the model. When the demand decreases, the total costs for these two components are the same, while they are divided over a much smaller group of consumers. On the other hand, when the demand increases, the capacity of the heat transport network and the heat sources is too low, and the system is actually infeasible. The model does not automatically report this. The change in the composition of the investment costs is more clearly visible in the following figure.

It is necessary to check the capacity of the base-load plants and primary heat infrastructure separately.

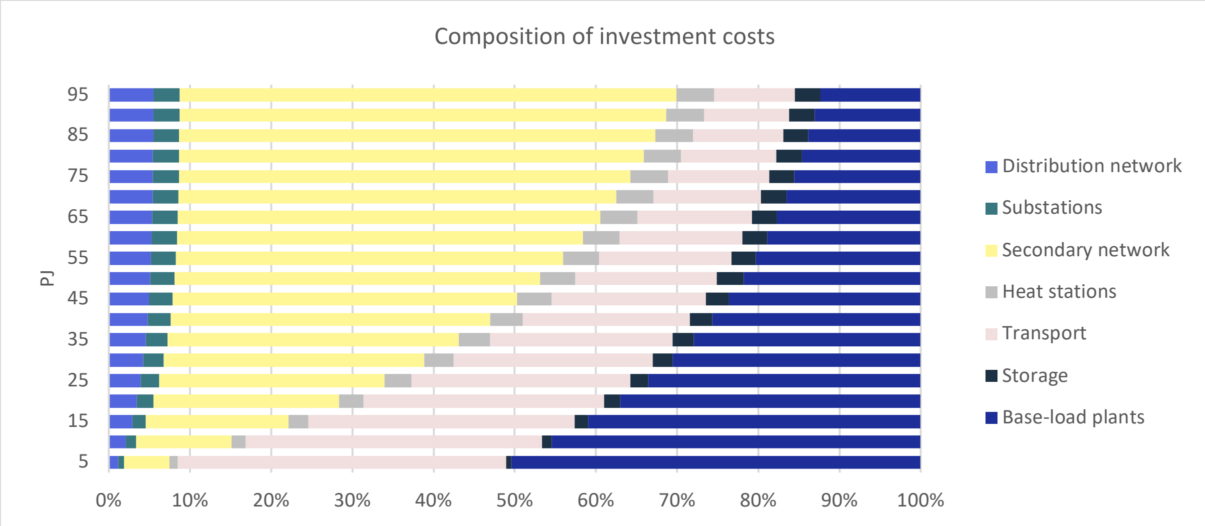


Figure 59 The composition of the investment costs of the district heating system

A.3.2 SENSITIVITY ANALYSIS

The heat demand, length, route and capacity of the primary heat transport infrastructure and the available heat supply are model inputs to calculate the investment costs. In the sequel, the sensitivity of the model outcome for these model inputs is tested. The sensitivity analysis is based on a model with the following assumptions:

Table 59 Overview of the assumptions of the base-case model verification

Variable	Assumption
Demand	50% of the demand in each cluster is connected to the DH network
Available supply	All residual heat sources are available and the development of geothermal heat is high.
Pipeline capacities	Pipeline capacities vision Province of South Holland, when necessary increased to ensure a min. available base-load supply capacity per cluster of 30% of the peak demand.

A.3.2.1 DEMAND

The figure displayed hereafter shows that the investment costs for most system components depend on the length of the network. The investment costs largely depend on the demand.

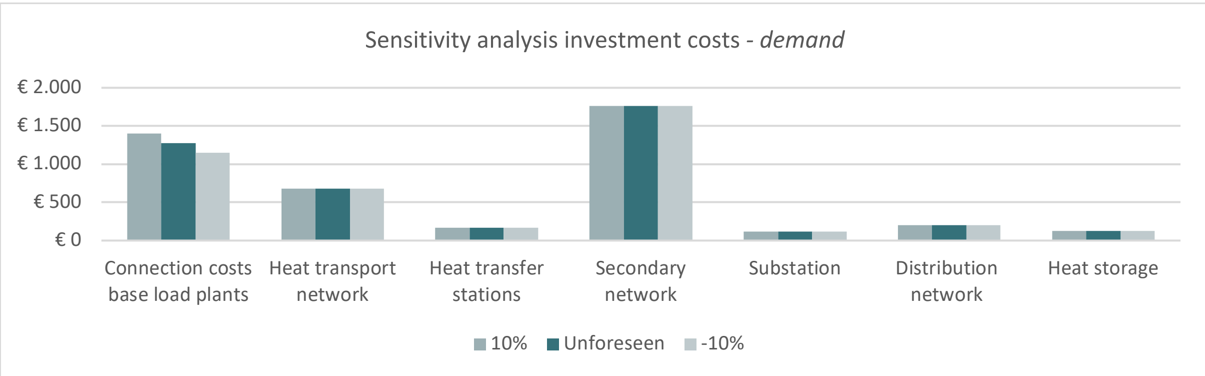


Figure 60 Output sensitivity analysis: Demand

A.3.2.2 DENSITY OF DEMAND

In the following figure, the sensitivity of the investment cost with respect to the density of the demand is given.

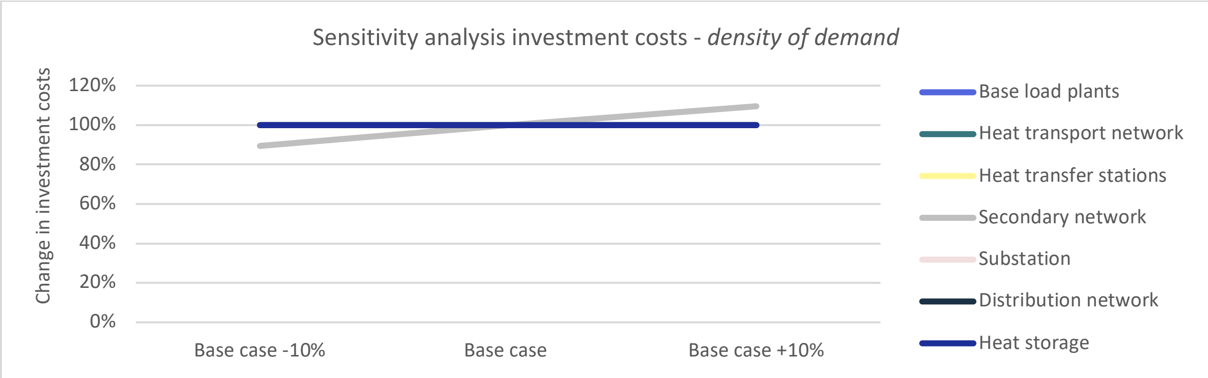


Figure 61 Sensitivity analysis investment costs - density of demand

A.3.2.3 SUPPLY

When the available heat supply is increases or decreased by 10%, the total investment costs change by 2%. This is mainly because of the investment costs in geothermal heat. While geothermal heat only represents 18% of the available base-load supply, it represents 63% of the investment costs. The total investment costs are sensitive to the development of geothermal heat, as shown in the following figure.

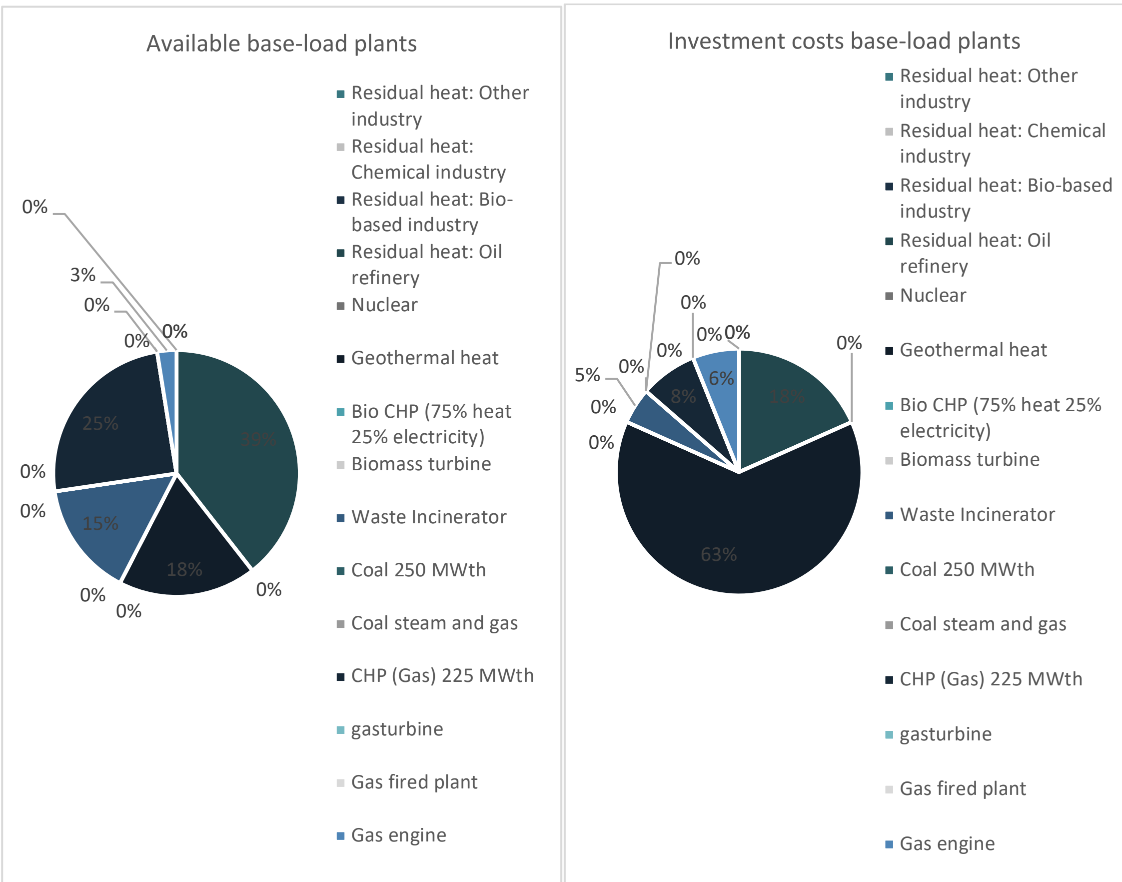


Figure 62 Share of available base-load plants and investment costs of the base-load plants

A.3.2.4 TRANSPORT

The investment costs for the heat transport network linearly depend on the length of the network. Economies of scale are not included in the model. The investment costs for the heat transport network only partially depend on the capacity of the pipeline. The length of the network depends on the distance between demand and supply, but also on the detour-factor. The detour factor indicates how much additional length of pipeline is necessary to bypass obstacles between supply and demand. The used detour factor for the primary and secondary infrastructure is 1,5. But literature suggests detour factors between 1,3 and 1.7 (Rooijers et al., 2002). The following figure shows that the actual route of the pipeline can have a relatively high impact on the investment costs for the heat transport network.

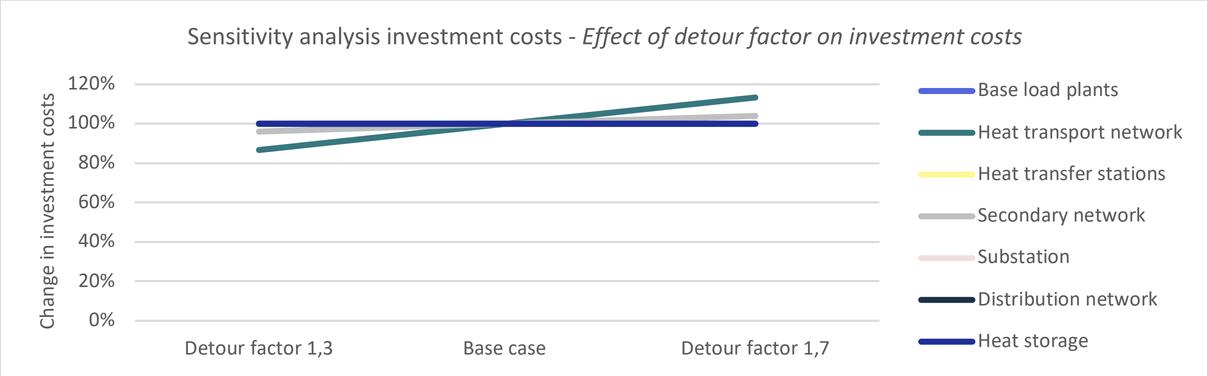


Figure 63 Sensitivity of the detour factor on investment costs

A.3.2.5 CONCLUSION

The model for the investment costs is sensitive to the demand, density of the demand, length and capacity of the transport network and the total availability of geothermal heat.

APPENDIX 4: SENSITIVITY ANALYSIS OF THE DISPATCH MODEL

This appendix contains a report on the sensitivity analysis of the dispatch model.

A.4.1 DEMAND PATTERN

The expert review indicated that the demand pattern for households and utility buildings is flatter than expected based on actual demand data from district heating networks in The Netherlands. This is the result of averaging the hourly demand over 10 years. To determine the effect of a demand pattern with higher peak demands, a demand pattern was constructed based on the average demand per hour in Rotterdam over 10 years, however now the data was first sorted from lowest temperature to highest temperature. Now the peak-demands are not averaged out. The figure below depicts the new and old demand patterns for the households and utility buildings.

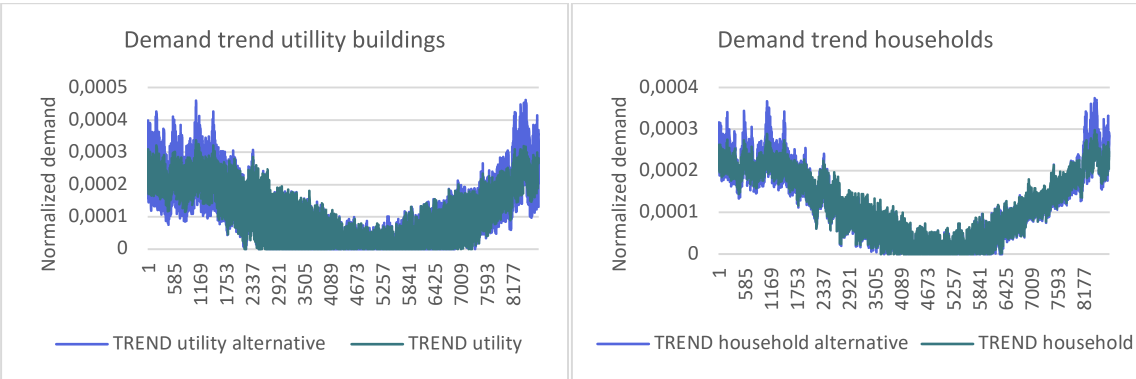


Figure 64 Normalized trend and alternative trend for the heat demand of households and utility buildings

This new demand pattern was tested on the base-case. The following table shows the effect of the alternative trend for the heat demand of households and utility buildings on the demand characteristics and key model inputs.

Table 60 Effect of the alternative trend for the heat demand on the key-figures

Change category	Peak demand	Base load demand	Total demand	Heat loss network
Leiden	125%	125%	101%	108%
Lansingerland	107%	107%	101%	108%
Rotterdam North	127%	127%	107%	162%
Dordrecht	125%	125%	101%	108%
Rotterdam South	127%	127%	100%	101%
The Hague	100%	100%	101%	106%

The base-load, peak-load, min. capacity of the peak boiler and heat losses in Leiden, Rotterdam North, Dordrecht and Rotterdam South are sensitive for the demand pattern of utility buildings and households. In Lansingerland and The Hague this effect is much smaller. This can be attributed to the large heat demand by greenhouses in these clusters.

The next table shows the effect of the alternative demand pattern on the necessary pipeline capacities.

Table 61 Effect of the alternative demand pattern on necessary pipeline capacities

Route	Min. pipeline capacities (used demand patterns)	Min. pipeline capacities alternative demand pattern	Change
LL-LEI	40	40	-
RN-LL	40	145	+263%
BO-RN	95	95	-
BO-RS	76	114	+51%
BO-DH	218	291	+33%
EU-BO	200	200	-
RS-DO	40	40	-

Higher base-loads can also have an effect on the required minimum capacity of the heat transport infrastructure. In the base-case, the pipeline capacity between Botlek and The Hague needs to be increased with 33%. Between Botlek and Rotterdam South the capacity needs to be increased by 51% and the pipeline capacity between Rotterdam North and Lansingerland needs to be increased with 265%. The other pipeline capacities are not sensitive for this new demand pattern. These larger pipeline capacities result in additional investment costs of approximately 15,6 million euro. The alternative demand pattern has no other effects on the total investment costs.

The alternative demand pattern, including new values for the pipeline capacities and peak boilers is implemented in the dispatch model. This leads to a slightly lower system efficiency but also to slightly lower CO_2 emissions per supplied MWh of heat. Because of the slightly steeper peak-demand, the model depends less hours per year on the peak boilers. In addition, because of the higher pipeline capacities the model can make better use of the (low-emission) residual heat in the Botlek.

Table 62 Output base-case and alternative demand pattern

	Standard demand pattern	Alternative demand pattern
% demand connected	50%	50%
Demand (MWh)	13904611	13904611
System efficiency (%)	83,9%	82,9%
Total CO2 emissions (ton)	613537	571950
CO2 density production (kg/MWh)	37,0	34,1
CO2 density supply (kg/MWh)	44,1	41,1
CO2 abatement (%)	77,1%	78,6%

The system design is very sensitive for the demand pattern of households and utility buildings. Especially when these two consumer groups make-up for the largest part of the heat demand within a cluster. Besides this, the demand pattern is uncertain. However, the model outputs do not deviate strongly in terms of CO_2 abatement and total investment costs. So independent of the demand pattern, the model finds similar costs of CO_2 abatement.

A.4.2 TOTAL DEMAND PER CLUSTER

In the following figure, the effect of the change in the demand per cluster on the overall CO_2 emissions is shown. The model is not equally sensitive to changes in the demand in all clusters. The model is most sensitive to changes in the demand in Lansingerland and Leiden. In addition, the model is the least sensitive to changes in the demand in Rotterdam North and Dordrecht.

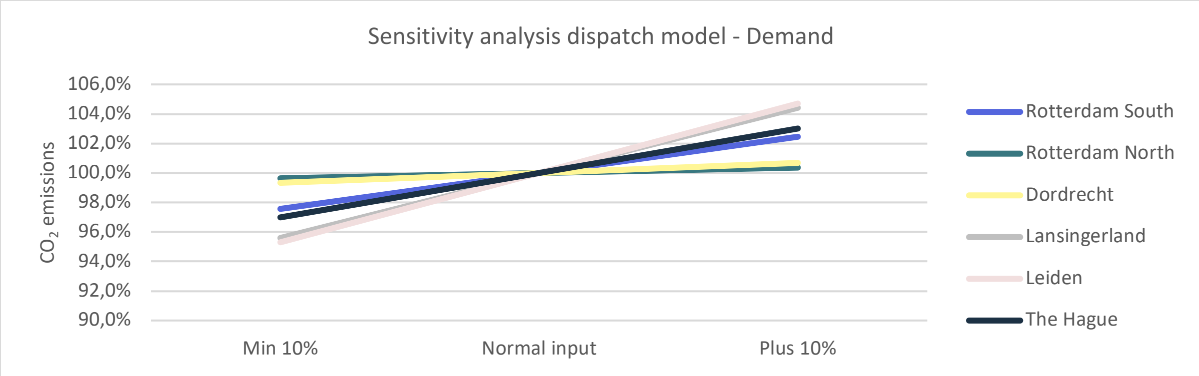


Figure 65 Output sensitivity analysis for varying demands per cluster

The following table shows that both in Leiden and in Lansingerland, the locally available base-production capacity is limited.

Table 63 Utilization of the available base-load plants

		Available supply (MW)	Average supply (MW)	Utilization
Botlek	Gas plant	717	0	0%
	Residual heat oil industry	500	443	89%
	Waste Incinerator	387	0	0%
Europort	Coal plant	1178	0	0%
	Gas plant	219	0	0%
	Residual heat oil industry	125	5	4%
The Hague	Geothermal	163	161	99%
	Gas plant	76	53	70%
	Gas Engine	15	10	67%
	Peak Boiler	1629	364	22%
Dordrecht	Geothermal	25	25	99%
	Waste Incinerator	113	66	58%
	Peak Boiler	176	0	0%
	Geothermal	25	25	98%
Leiden	Gas plant	83	66	79%
	Peak Boiler	358	109	31%
Lansingerland	Geothermal	75	74	99%
	Gas Engine	10	10	100%
	Peak Boiler	548	90	16%
Rotterdam North	Gas plant	340	109	32%
	Peak Boiler	167	0	0%
Rotterdam South	Gas Engine	10	7	70%
	Waste Incinerator	126	107	85%
	Peak Boiler	591	172	29%

Moreover, the table hereafter shows that the infrastructure towards Lansingerland forms a bottleneck. The pipeline capacity towards Lansingerland is designed to supply heat to both Lansingerland and Leiden, where most of the heat is consumed in Lansingerland. The heat is only transported to Leiden when the demand in Leiden can be supplied independent of the peak boiler.

Table 64 Overview of the utilization of the transport capacity

Route	% capacity used
LL-LEI	10%
RN-LL	83%
BO-RN	96%
BO-RS	100%
BO-DH	84%
EU-BO	0%
RS-DO	12%

An increase in the demand in these clusters means an increased dependence on the peak boiler or heat import, but the heat import towards Lansingerland is designed close to its maximum. The increased dependence on the peak boilers results in higher CO_2 emissions.

A.4.3 AVAILABILITY OF HEAT SOURCES

The figure below shows the effect of an increase or decrease of the available capacity for the plants in each cluster on the overall CO_2 emissions. In line with the sensitivity of the demand, the model is especially sensitive for the capacity of the heat sources in Lansingerland and in Leiden.

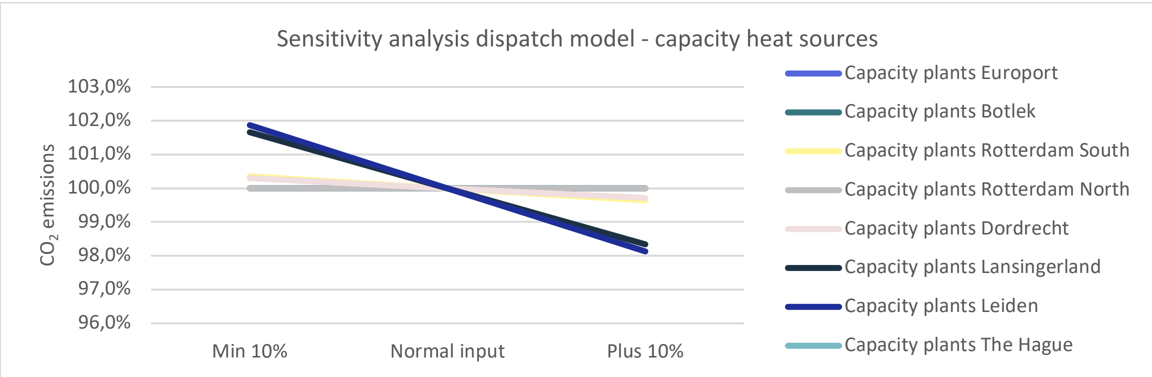


Figure 66 Output sensitivity analysis of the dispatch model: production capacity per plant

The sensitivity of the CO_2 emissions in the dispatch model thus depend on the balance between locally available demand and supply, including the available heat imports.

A.4.3.1 GEOTHERMAL HEAT

The availability of geothermal heat is very uncertain, not only because it is uncertain how many geothermal wells will be developed, but also because the heat capacity of these wells is uncertain. The model is currently based on the assumption that each geothermal well has a thermal capacity of 12,5 MW. A sensitivity analysis on the thermal capacity of the geothermal heat sources shows that the overall CO_2 emissions are sensitive to the thermal capacity per well. An increase or decrease of the thermal capacity per well of 10% results in a relative decrease or increase of the total CO_2 emissions of almost 4%.

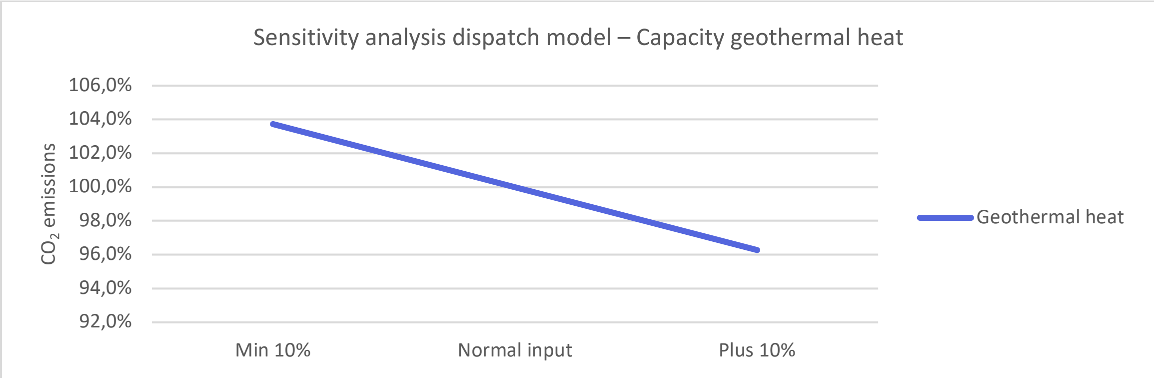


Figure 67 Output Sensitivity analysis of the dispatch model: capacity geothermal heat

Appendix 5: Approach for calculating the minimum capacities for the main transport infrastructure

A.5.1 Min. capacity per pipeline in MW

The following table provides a validation of the base-load and peak-load requirements.

Table 65 Overview check of the base-load and peak-load requirements

	Vesta	Min. Geo 25%	Max geo + 50%	Min. geo +50%	Min geo +80%		Vesta	Min. Geo + 25%	Max geo + 50%	Min. geo +50%	Min geo +80%		Vesta	Min. Geo 25%	Max geo + 50%	Min. geo +50%	Min geo +80%
BASE LOAD SUPPLY						BASE LOAD DEMAND (60% peak demand)						SHORTAGE/OVER CAPACITY BASE LOAD					
BO	1729	1729	1729	1729	1729	BO						BO		1729	1729	1729	1729
EU	1397	1397	1397	1397	1397	EU						EU		1397	1397	1397	1397
LEI	88	108	183	108	108	LEI	43	126	253	253	575	LEI	45	-18	-70	-145	-467
LL	15	90	165	90	90	LL	349	193	387	387	996	LL	-334	-103	-222	-297	-906
RN	345	340	340	340	340	RN	28	59	118	118	270	RN	316	281	222	222	70
DO	120	138	188	138	138	DO	20	62	124	124	283	DO	100	76	64	14	-145
RS	138	136	136	136	136	RS	197	209	417	417	951	RS	-59	-73	-281	-281	-815
DH	135	254	366	254	254	DH	143	575	1150	1150	2645	DH	-9	-321	-784	-896	-2392
	3966	4192	4504	4192	4192												
STORAGE 4.2% AVERAGE DAILY DEMAND																	
LEI	24	107	213	213	342												
LL	161	135	269	269	431												
RN	16	46	92	92	147												
DO	11	52	104	104	167												
RS	109	175	349	349	558												
DH	78	433	865	865	1385												
PEAK LOAD SUPPLY 85% MAX DEMAND						PEAK LOAD DEMAND (70% peak demand)						SHORTAGE/OVER CAPACITY PEAK LOAD					
LEI	61	179	358	358	815	LEI	50	147	295	295	671	LEI	11	32	63	63	144
LL	495	274	548	548	1411	LL	408	226	451	451	1162	LL	87	48	97	97	249
RN	40	84	167	167	382	RN	33	69	138	138	315	RN	7	15	30	30	67
DO	29	88	176	176	400	DO	24	72	145	145	330	DO	5	16	31	31	71
RS	279	295	591	591	1348	RS	230	243	487	487	1110	RS	49	52	104	104	238
DH	203	814	1629	1629	3747	DH	167	671	1341	1341	3086	DH	36	144	287	287	661
TOTAL SUPPLY						PEAK DEMAND						TOTAL SHORTAGE/OVER CAPACITY					
BO	1729	1729	1729	1729	1729	BO						BO	1729	1729	1729	1729	1729
EU	1397	1397	1397	1397	1397	EU						EU	1397	1397	1397	1397	1397
LEI	149	287	541	466	923	LEI	93	274	547	547	1246	LEI	56	267	-82	-82	-323
LL	510	364	713	638	1501	LL	757	419	838	838	2158	LL	-247	294	-200	-200	-657

RN	385	424	507	507	722	RN	61	128	256	256	584	RN	323	379	251	251	138
DO	149	226	364	314	538	DO	44	134	269	269	612	DO	105	229	45	45	-74
RS	417	431	727	727	1484	RS	427	452	904	904	2061	RS	-10	275	-177	-177	-578
DH	338	1068	1995	1882	4001	DH	310	1245	2491	2491	5731	DH	27	749	-609	-609	-1730

A.5.2 DN EQUIVALENT PIPELINE

In this section, the capacities of the standard DN pipelines are computed. The capacity of the pipeline is given by

$$P = \eta \, \rho \, c \, \Delta T,$$

where P is the capacity, η denotes the volume that flows through the pipe, c is the specific heat of the fluid and ΔT is the temperature difference. The volume that flows through the pipe is calculated by

$$\eta = \frac{1}{4}\pi D^2 v,$$

with D denotes the diameter of the pipe and v is the flow speed of the fluid. The table below highlights the assumed coefficient.

Table 66 Assumed coefficients to obtain the pipeline capacities

	Value	Units
Temperature difference ΔT	20	K
Flow speed v	3	m/s
Specific mass water (70°C) ρ	977	kg/m^3
Specific heat water c	4,2	J/(kg*K)

Based on the aforementioned equations and table, the capacity of the pipelines for standard DN pipelines can be obtained. The capacities are given in the table below.

Table 67 Capacities of the standard DN pipelines

DN standard	Outer diameter (mm)	Wall thickness (mm)	Inner diameter (mm)	Flow (m^3)	Capacity (W)	MWh
20	26,9	2,3	22,3	0,001	96	0
25	33,7	2,6	28,5	0,002	157	1
32	42,4	2,6	37,2	0,003	268	1
40	48,3	2,6	43,1	0,004	359	1
50	60,3	2,9	54,5	0,007	574	2
65	76,1	2,9	70,3	0,012	956	3
80	88,9	3,2	82,5	0,016	1316	5
100	114,3	3,6	107,1	0,027	2218	8
125	139,7	3,6	132,5	0,041	3395	12
150	168,3	4	160,3	0,061	4969	18
200	219,1	4,5	210,1	0,104	8536	31
250	273	5	263	0,163	13375	48
300	323,9	5,6	312,7	0,230	18908	68
350	355,6	5,6	344,4	0,279	22936	83

APPENDIX 6: MODEL RESULTS

This appendix contains the dispatch model results for the four scenarios.

A.6.1 OVERVIEW OF THE FLOW THROUGH THE NETWORK

In the following table, the left column shows the average hourly heat production in MW and the right column shows the composition of the heat production and export/import within the cluster, for each of the scenarios.

Table 68 Flow of heat through the network

		The PBL		**The PZH**					
		Distributed		Limited		Unforeseen		Abundance	
Europort	Coal plant	0		0		0		0	
	Gas plant	0		0		0		0	
	Residual heat oil industry	0		0		5		0	
	Export	0		0		-5		0	
	Sum	0		0		0		0	
Botlek	Gas plant	0		0		0		0	
	Residual heat oil industry	0		192		443		331	
	Waste Incinerator	0		0		0		0	
	Import	0		0		5		0	
	Import loss	0		0		0		0	
	Export			-192		-448		-331	
	Sum	0		0		0		0	
The Hague	Small CHP	1	1%	0	0%	0	0%	0	0%
	Geothermal	38	43%	152	35%	161	19%	263	31%
	Gas plant	41	46%	51	12%	53	6%	53	6%
	Gas Engine	5	5%	9	2%	10	1%	10	1%
	Peak Boiler	5	5%	149	35%	364	42%	364	42%
	Import		0%	71	17%	281	33%	176	20%
	Import loss	0	0%	-3	-1%	-11	-1%	-7	-1%
	Sum	90		430		859		859	
Rotterdam North	Small CHP	0	0%	0	0%	0	0%	0	0%
	Gas plant	146	811%	8	17%	109	120%	44	48%
	Peak Boiler	0	0%	0	0%	0	0%	0	0%
	Import		0%	72	158%	91	100%	80	88%
	Import loss	0	0%	-3	-6%	-4	-4%	-3	-4%
	Export	-128	-711%	-31	-68%	-106	-116%	-30	-32%
	Sum	18		45		91		91	
Leiden	Geothermal	5	18%	25	23%	25	12%	92	43%
	Gas plant	23	82%	51	48%	66	31%	53	25%
	Peak Boiler	0	0%	23	22%	109	52%	64	30%
	Import	0	0%	8	7%	13	6%	2	1%
	Import loss	0	0%	0	0%	-1	0%	0	0%
	Sum	27		106		212		212	
Lansingerland	Small CHP	0	0%	0	0%	0	0%	0	0%
	Geothermal	0	0%	68	52%	74	28%	133	50%
	Gas Engine	8	4%	9	7%	10	4%	6	2%
	Peak Boiler	53	29%	33	25%	90	34%	100	38%
	Import	128	69%	31	24%	106	40%	30	11%
	Import loss	-5	-3%	-1	-1%	-4	-2%	-1	0%
	Export		0%	-8	-6%	-13	-5%	-2	-1%
	Sum	185		132		263		266	
Rotterdam South	Small CHP	1	0%	0	0%	0	0%	0	0%
	Geothermal	2	1%	0	0%	0	0%	0	0%
	Gas Engine	5	4%	5	3%	7	2%	7	2%
	Waste Incinerator	94	75%	88	50%	107	30%	104	30%
	Peak Boiler	24	19%	36	21%	172	49%	163	47%
	Import		0%	49	28%	76	21%	76	22%
	Import loss	0	0%	-2	-1%	-3	-1%	-3	-1%
	Export		0%	0	0%	-5	-1%	0	0%
	Sum	125		176		355		346	
Dordrecht	Small CHP	0	0%	0	0%	0	0%	0	0%
	Geothermal	2	13%	23	45%	25	26%	63	61%
	Waste Incinerator	11	87%	26	50%	66	69%	40	39%

	Peak Boiler	0	0%	0	0%	0	0%	0	0%
	Import		0%	3	5%	5	5%	0	0%
	Import loss	0	0%	0	0%	0	0%	0	0%
	Sum	13		52		96		103	

A.6.2 UTILIZATION OF THE PLANTS

The table below shows an overview of the heat production per type of plant, for each cluster in each of the four scenarios. For each plant, the table shows the available capacity, the average production, the utilization rate of the plant and the composition of the heat production within each cluster.

Table 69 Overview of the production per type of plant per cluster for each scenario

	Distributed				**Limited**				**Unforeseen**				**Abundance**			
	Available	Average supply	Utilization rate	Composition supply	Available	Average supply	Utilization rate	Composition supply	Available	Average supply	Utilization rate	Composition supply	Available	Average supply	Utilization rate	Composition supply
Botlek																
Bio CHP								0%				0%				0%
Coal plant								0%				0%				0%
Geothermal								0%				0%				0%
Gas engine								0%				0%				0%
Gas plant	0,00	0,00			717,00	0,00	0%	0%	717,00	0,00	0%	0%	717,00	0,00	0%	0%
Residual heat oil industry	0,00	0,00			500,00	192,35	38%	100%	500,00	443,20	89%	100%	500,00	331,47	66%	100%
Waste Incinerator	0,00	0,00			387,00	0,00	0%	0%	387,00	0,00	0%	0%	387,00	0,01	0%	0%
Peak Boiler																
Europort																
Bio CHP												0%				0%
Coal plant	0,00	0,00			1178,00	0,00	0%		1178,00	0,00	0%	0%	1178,00	0,00	0%	0%
Geothermal												0%				0%
Gas engine												0%				0%
Gas plant	0,00	0,00			219,00	0,00	0%		219,00	0,00	0%	0%	219,00	0,00	0%	0%
Residual heat oil industry		0,00			125,00	0,00			125,00	4,84	4%	100%	125,00	0,01	0%	100%
Waste Incinerator												0%				0%
Peak Boiler												0%				0%
The Hague																
Bio CHP	2,30	0,84	36%	1%	0,00			0%	0,00			0%				0%
Coal plant				0%				0%				0%				0%
Geothermal	41,30	38,25	93%	43%	162,50	152,47	94%	42%	162,50	161,38	99%	27%	275,00	262,86	96%	38%
Gas engine	15,00	4,76	32%	5%	15,00	9,19	61%	3%	15,00	10,07	67%	2%	15,00	10,05	67%	1%
Gas plant	76,00	41,12	54%	46%	76,00	50,63	67%	14%	76,00	53,49	70%	9%	76,00	53,42	70%	8%
Residual heat oil industry				0%				0%				0%				0%
Waste Incinerator				0%				0%				0%				0%

Peak Boiler	171,00	4,82	3%	5%	814,00	149,25	18%	41%	1629,00	364,47	22%	62%	1629,00	364,14	22%	53%
Dordrecht																
Bio CHP	5,40	0,00	0%	0%				0%				0%				0%
Coal plant				0%				0%				0%				0%
Geothermal	1,70	1,70	100%	13%	25,00	23,01	92%	47%	25,00	24,87	99%	27%	75,00	63,22	84%	61%
Gas engine				0%				0%				0%				0%
Gas plant				0%				0%				0%				0%
Residual heat oil industry				0%				0%				0%				0%
Waste Incinerator	113,00	11,49	10%	87%	113,00	26,07	23%	53%	113,00	65,86	58%	72%	113,00	40,23	36%	39%
Peak Boiler	24,00	0,00	0%	0%	88,00	0,00	0%	0%	176,00	0,24	0%	0%	176,00	0,02	0%	0%
Leiden																
Bio CHP				0%				0%				0%				0%
Coal plant				0%				0%				0%				0%
Geothermal	4,80	4,80	100%	18%	25,00	24,62	98%	25%	25,00	24,52	98%	12%	100,00	91,93	92%	44%
Gas engine				0%				0%				0%				0%
Gas plant	83,00	22,50	27%	82%	83,00	51,24	62%	52%	83,00	65,89	79%	33%	83,00	53,46	64%	25%
Residual heat oil industry				0%				0%				0%				0%
Waste Incinerator				0%				0%				0%				0%
Peak Boiler	52,00	0,00	0%	0%	179,00	22,91	13%	23%	358,00	109,26	31%	55%	358,00	64,42	18%	31%
Lansingerland																
Bio CHP	0,40	0,21	54%	0%				0%				0%				0%
Coal plant				0%				0%				0%				0%
Geothermal				0%	75,00	68,41	91%	62%	75,00	74,02	99%	42%	150,00	133,35	89%	56%
Gas Engine	10,00	7,88	79%	13%	10,00	8,67	87%	8%	10,00	10,21	102%	6%	10,00	6,41	64%	3%
Gas plant				0%				0%				0%				0%
Residual heat oil industry				0%				0%				0%				0%
Waste Incinerator				0%				0%				0%				0%
Peak Boiler	417,00	52,89	13%	87%	274,00	33,02	12%	30%	548,00	90,18	16%	52%	548,00	100,30	18%	42%
Import		126,40														0%
Rotterdam North																
Bio CHP	3,40	0,00	0%	0%	0,00	0,00		0%				0%				0%
Coal plant				0%				0%				0%				0%
Geothermal				0%				0%				0%				0%
Gas engine				0%				0%				0%				0%
Gas plant	340,00	146,43	43%	100%	340,00	7,53	2%	100%	340,00	109,50	32%	100%	340,00	44,07	13%	100%
Residual heat oil industry				0%				0%				0%				0%
Waste Incinerator				0%				0%				0%				0%
Peak Boiler	33,00	0,00	0%	0%	84,00	0,00	0%	0%	167,00	0,00	0%	0%	167,00	0,03	0%	0%
Rotterdam South																
Bio CHP	1,20	0,59	49%	0%				0%				0%				0%
Coal plant				0%				0%				0%				0%
Geothermal	1,60	1,60	100%	1%				0%				0%				0%
Gas Engine	10,00	4,72	47%	4%	10,00	4,78	48%	4%	10,00	6,99	70%	2%	10,00	7,06	71%	3%

Gas plant				0%				0%				0%				0%
Residual heat oil industry				0%				0%				0%				0%
Waste Incinerator	126,00	94,14	75%	75%	126,00	87,81	70%	68%	126,00	107,13	85%	37%	126,00	103,61	82%	38%
Peak Boiler	235,00	24,07	10%	19%	295,00	36,09	12%	28%	591,00	172,39	29%	60%	591,00	162,89	28%	60%

A.6.3 UTILIZATION OF HEAT STORAGES

In this section, the stored heat of the heat storages per each cluster for each of the scenarios is given.

A.6.3.1 DISTRIBUTED

The stored heat of the heat storages is per cluster is given in the following figures based on the distributed scenario.

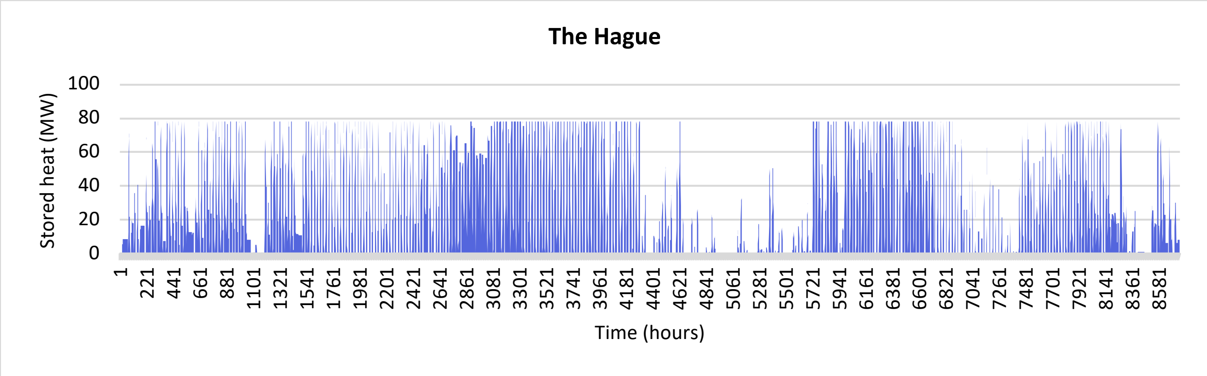


Figure 68 Hourly use of heat storage for The Hague in the Distributed scenario

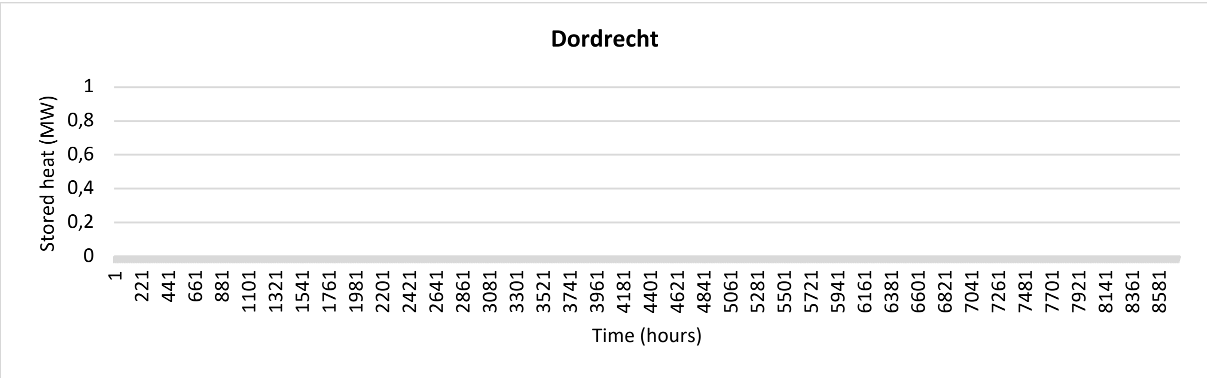


Figure 69 Hourly use of heat storage for Dordrecht in the Distributed scenario

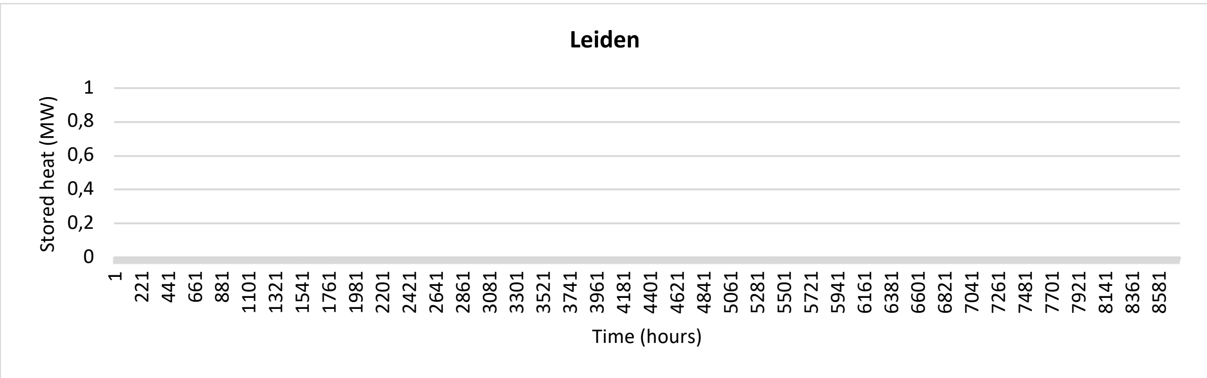


Figure 70 Hourly use of heat storage for Leiden in the Distributed scenario

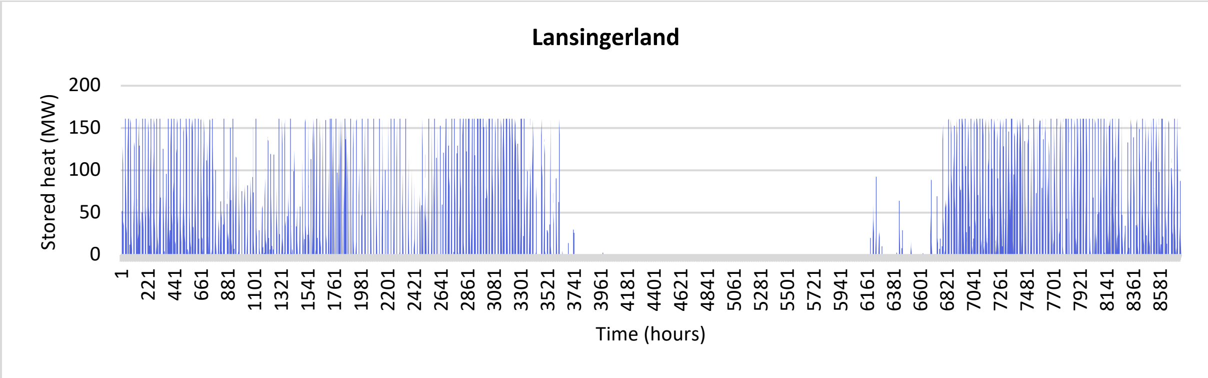


Figure 71 Hourly use of heat storage for Lansingerland in the Distributed scenario

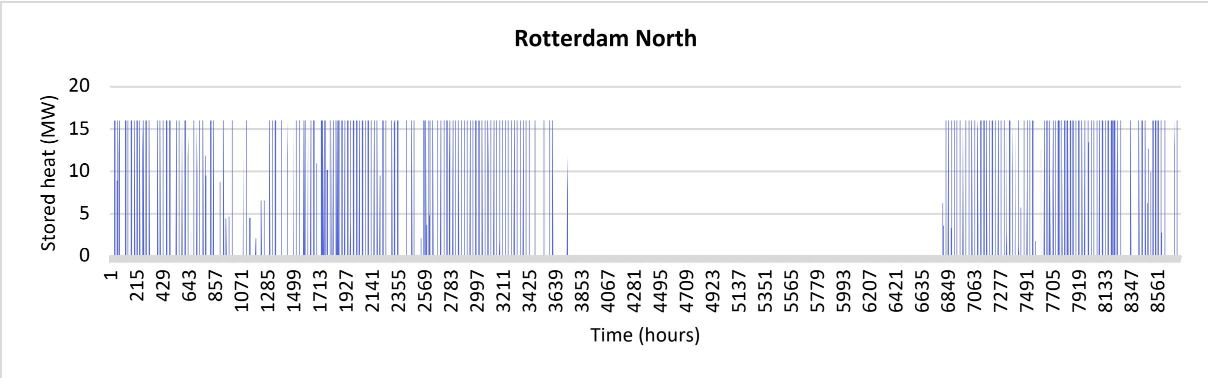


Figure 72 Hourly use of heat storage for Rotterdam North in the Distributed scenario

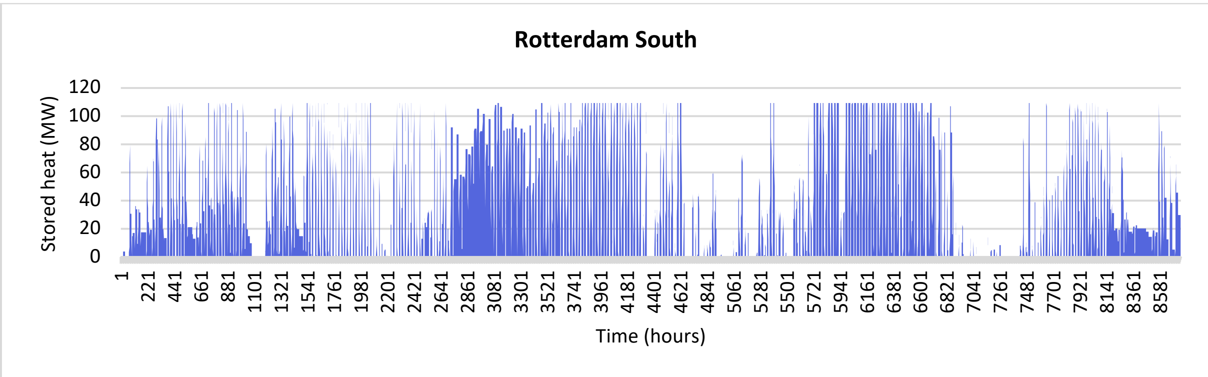


Figure 73 Hourly use of heat storage for Rotterdam South in the Distributed scenario

A.6.3.2 LIMITED

The stored heat of the heat storages is per cluster is given in the following figures based on the limited scenario.

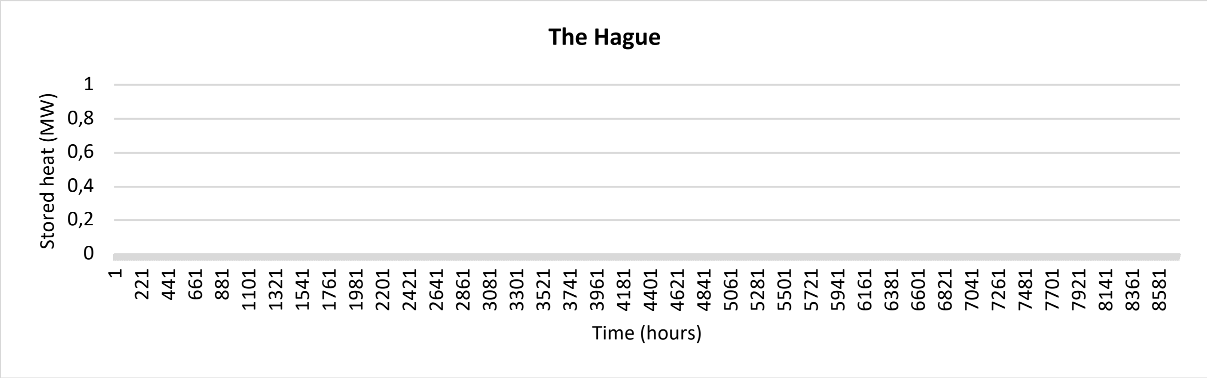


Figure 74 Hourly use of heat storage for The Hague in the Limited scenario

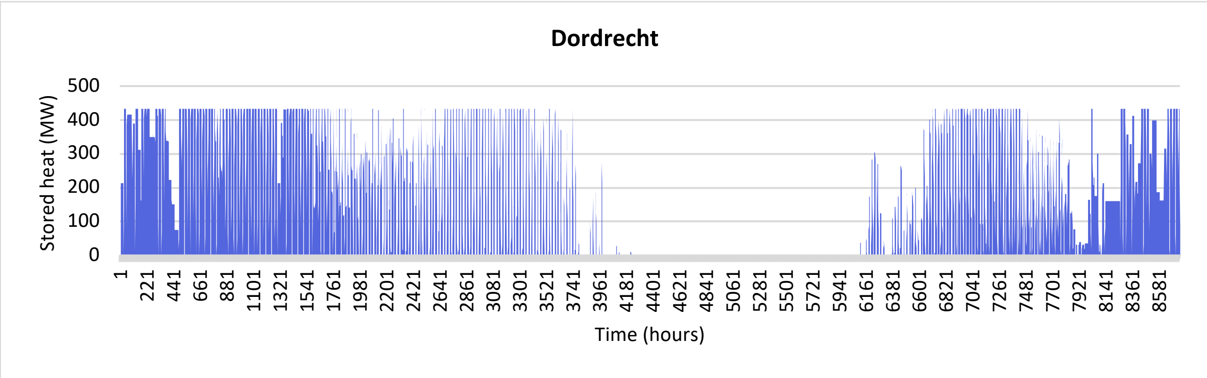


Figure 75 Hourly use of heat storage for Dordrecht in the Limited scenario

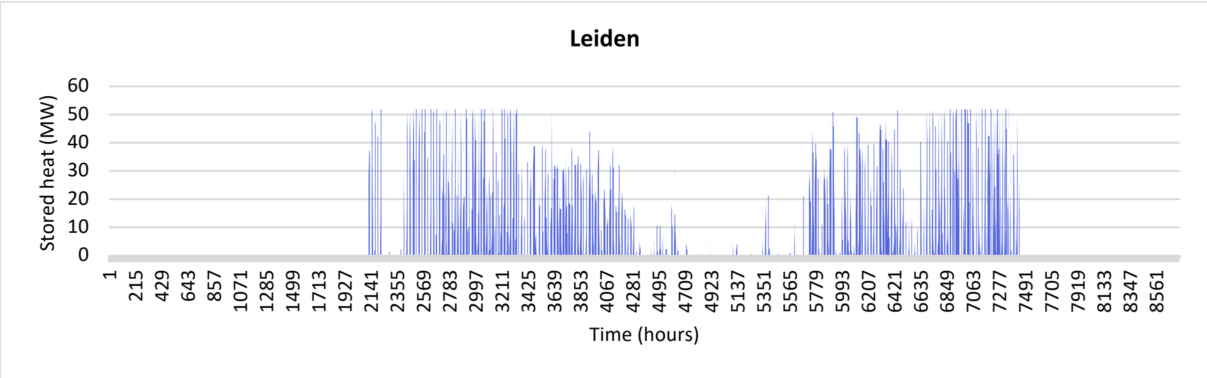


Figure 76 Hourly use of heat storage for Leiden in the Limited scenario

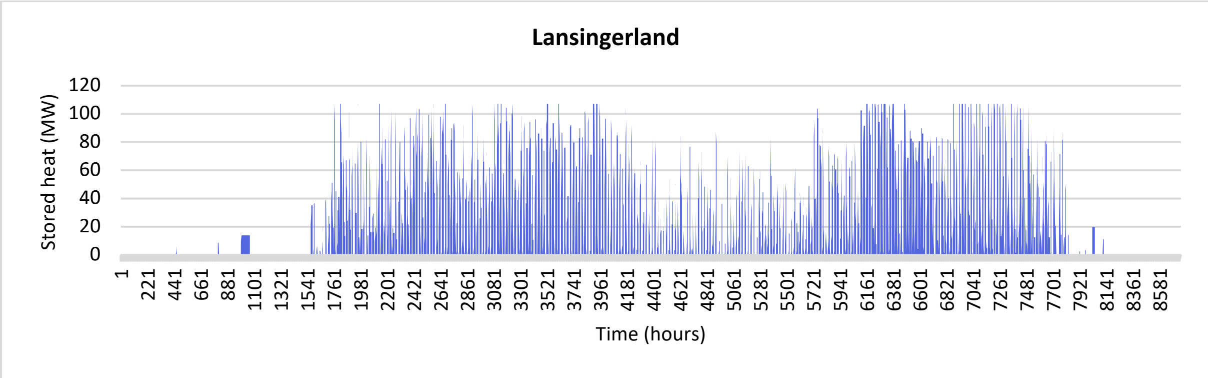


Figure 77 Hourly use of heat storage for Lansingerland in the Limited scenario

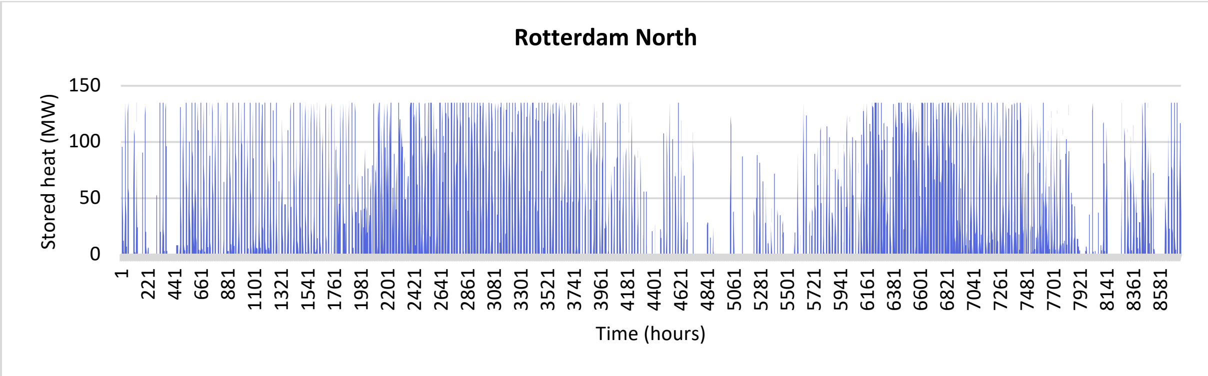


Figure 78 Hourly use of heat storage for Rotterdam North in the Limited scenario

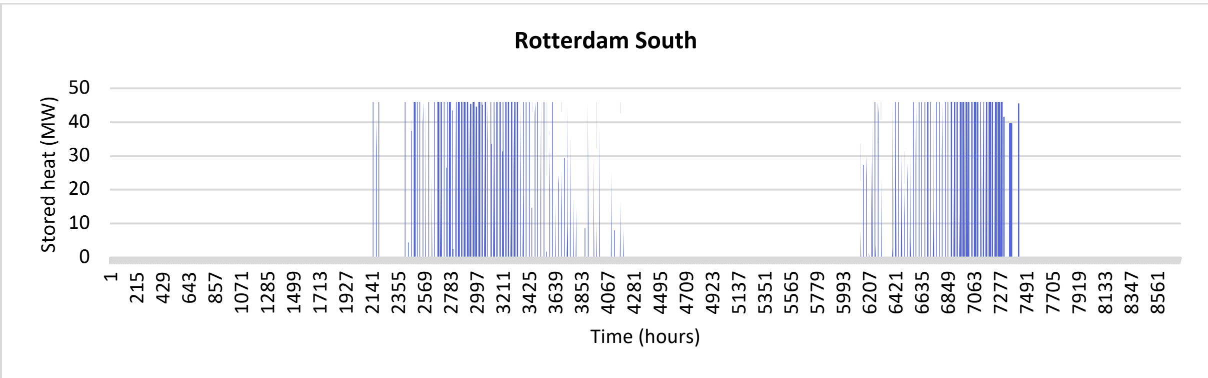


Figure 79 Hourly use of heat storage for Rotterdam South in the Limited scenario

A.6.3.3 UNFORESEEN

The stored heat of the heat storages is per cluster is given in the following figures based on the unforeseen scenario.

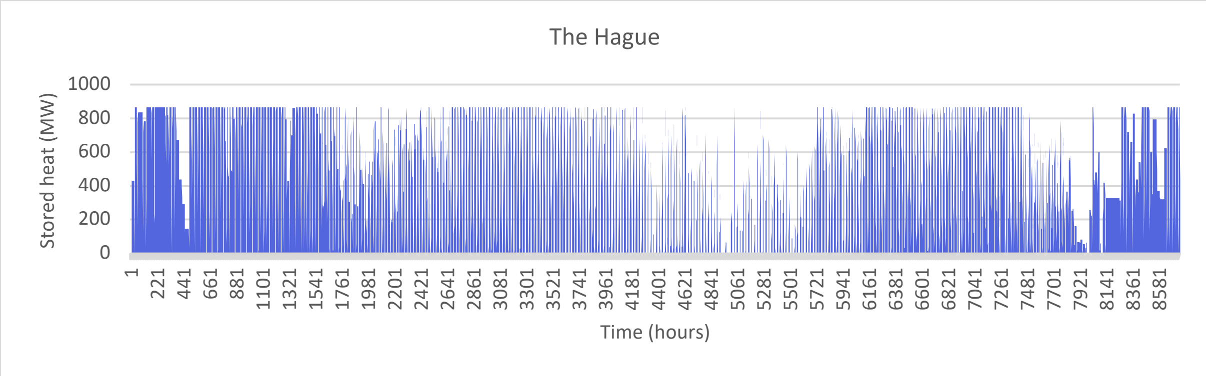


Figure 80 Hourly use of heat storage for The Hague in the Unforseen scenario

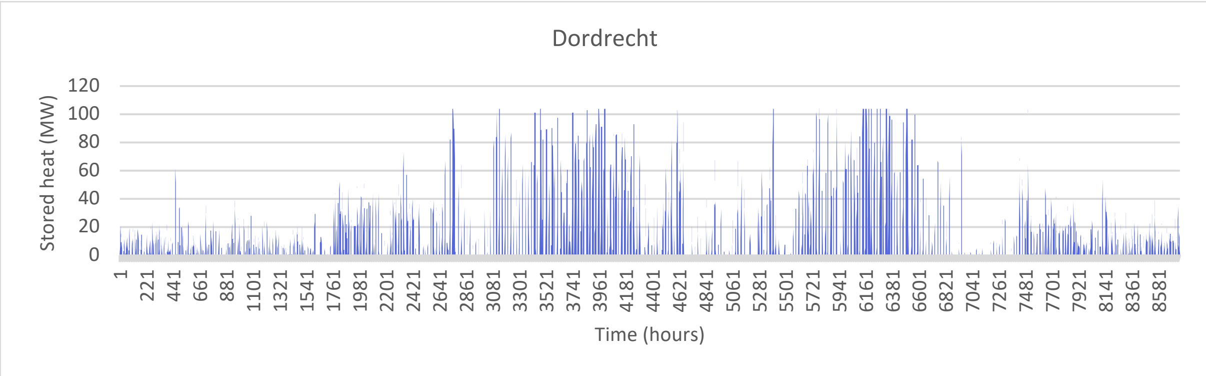


Figure 81 Hourly use of heat storage for Dordrecht in the Unforseen scenario

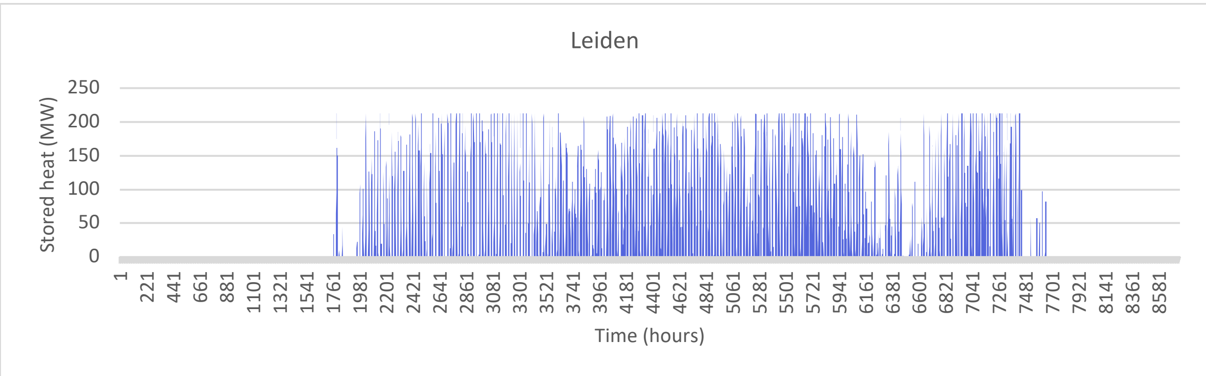


Figure 82 Hourly use of heat storage for Leiden in the Unforseen scenario

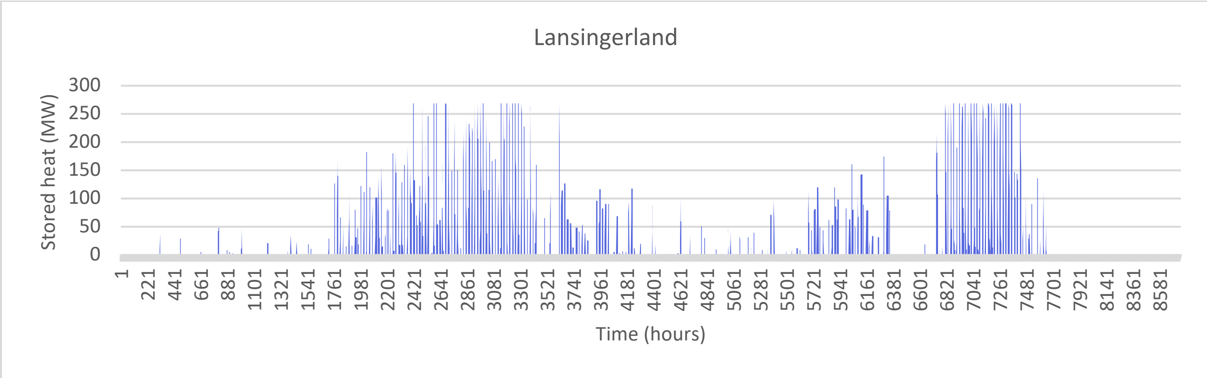


Figure 83 Hourly use of heat storage for Lansingerland in the Unforseen scenario

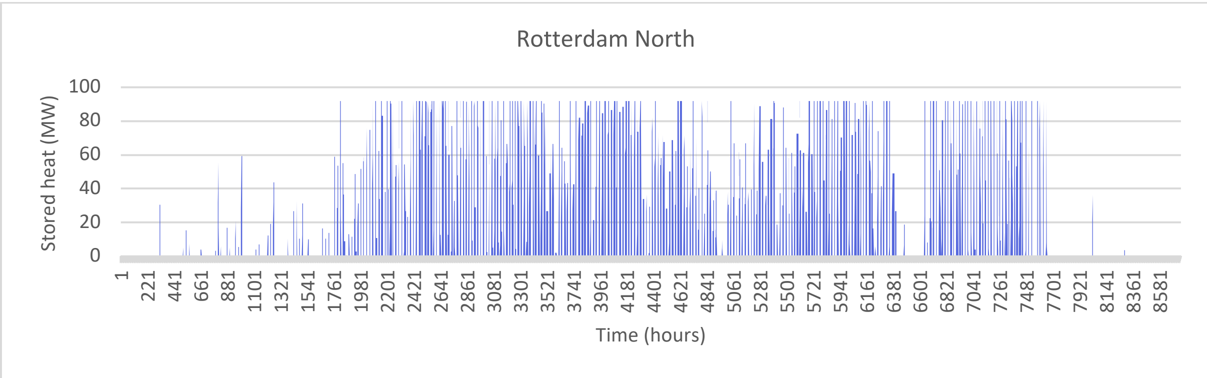


Figure 84 Hourly use of heat storage for Rotterdam North in the Unforseen scenario

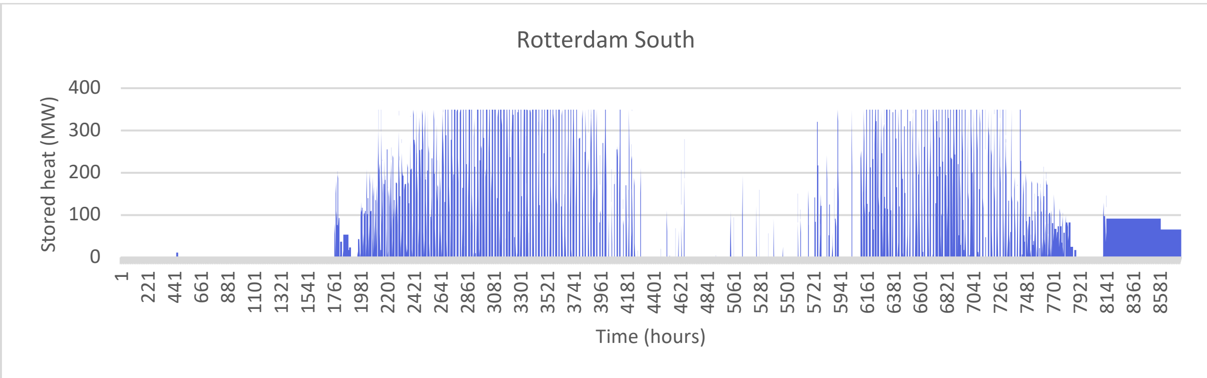


Figure 85 Hourly use of heat storage for Rotterdam South in the Unforseen scenario

A.6.3.4 ABUNDANCE

The stored heat of the heat storages is per cluster is given in the following figures based on the abundance scenario.

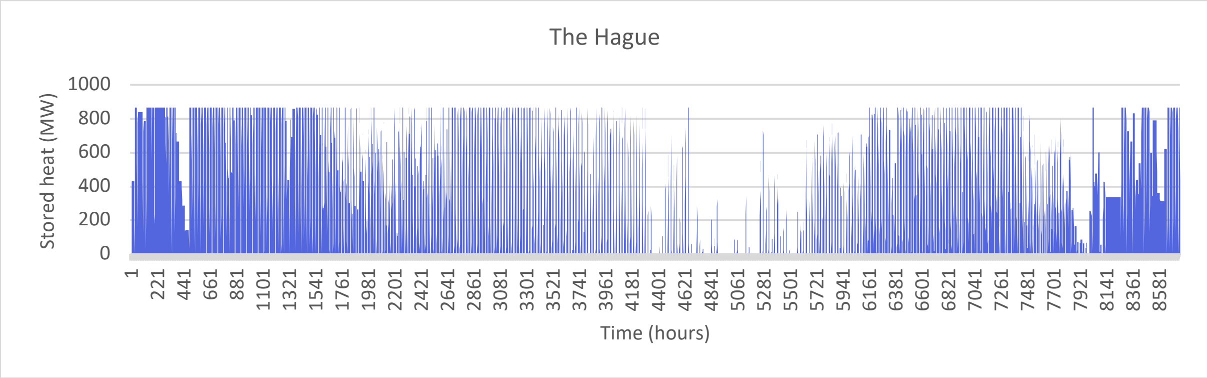


Figure 86 Hourly use of heat storage for The Hague in the Abundance scenario

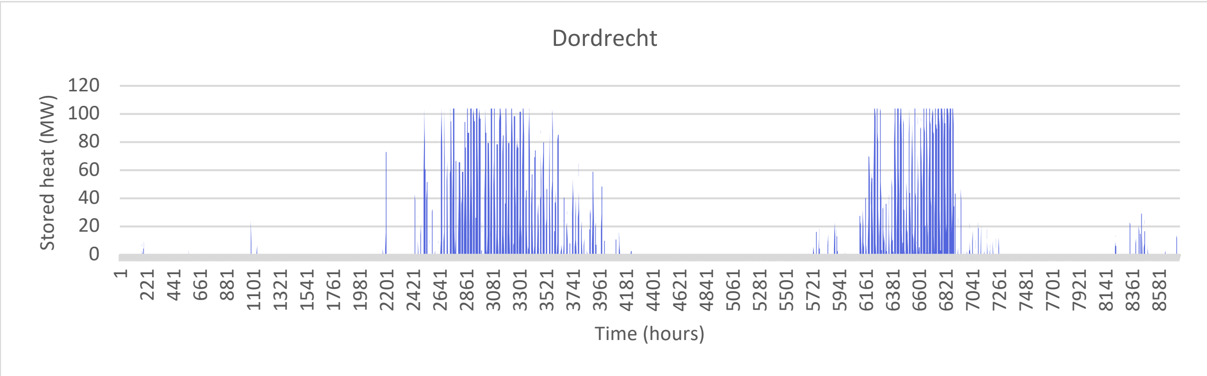


Figure 87 Hourly use of heat storage for Dordrecht in the Abundance scenario

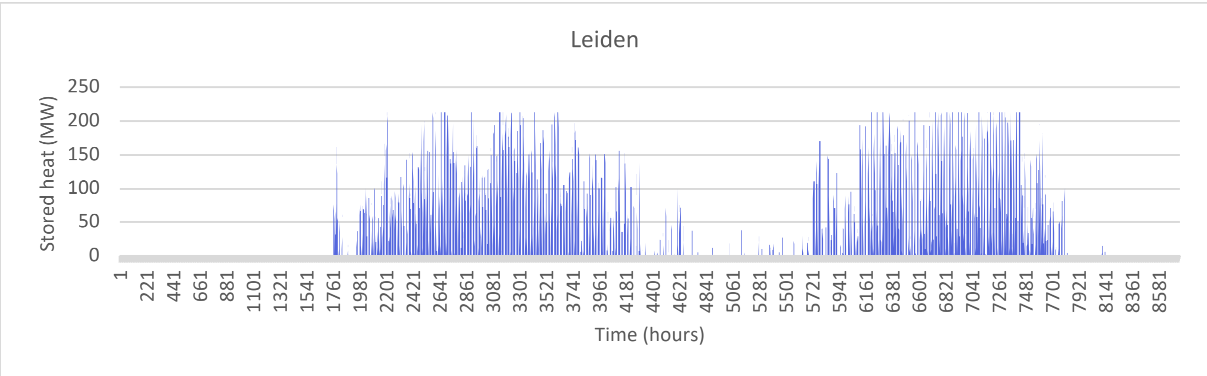


Figure 88 Hourly use of heat storage for Leiden in the Abundance scenario

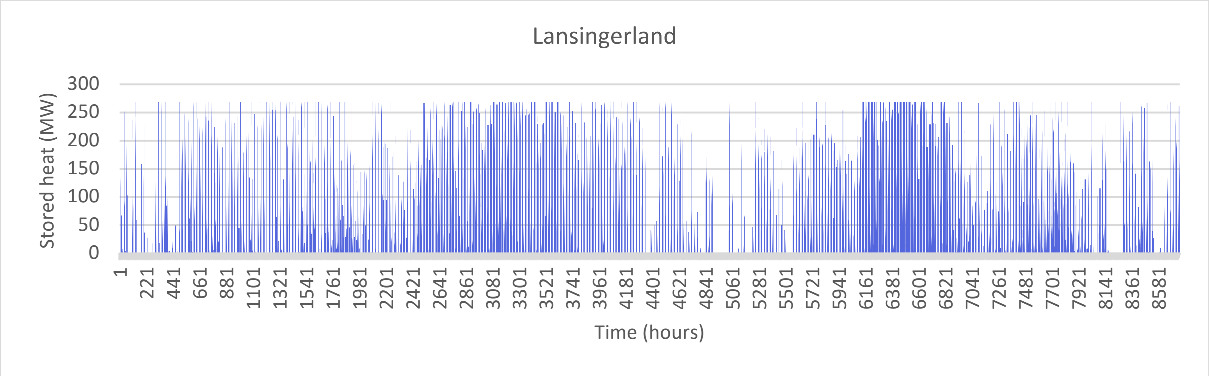


Figure 89 Hourly use of heat storage for Lansingerland in the Abundance scenario

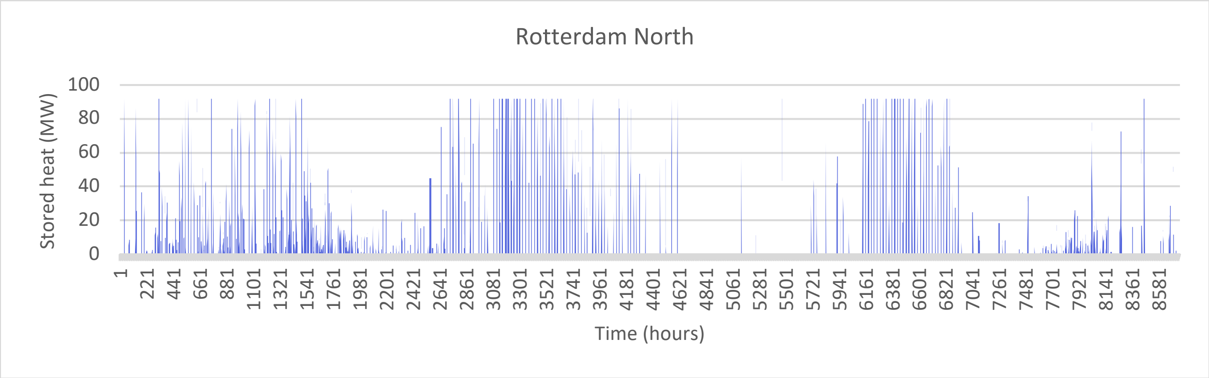


Figure 90 Hourly use of heat storage for Rotterdam North in the Abundance scenario

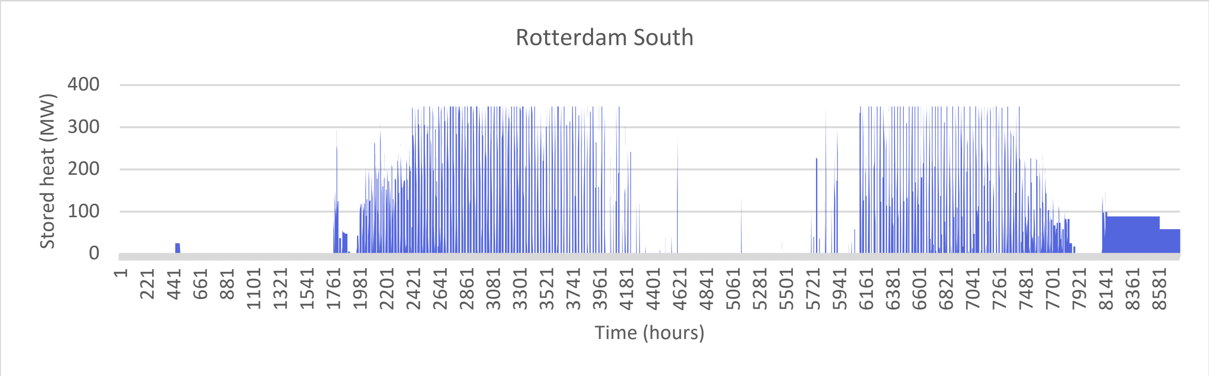
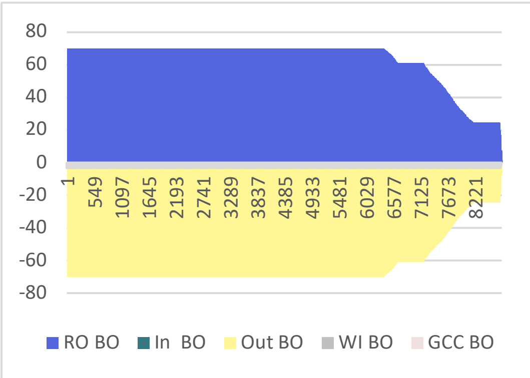


Figure 91 Hourly use of heat storage for Rotterdam South in the Abundance scenario

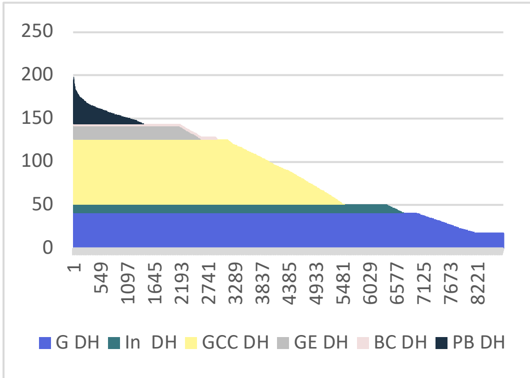
A.6.4 LOAD-DURATION CURVES

A.6.4.1 DISTRIBUTED

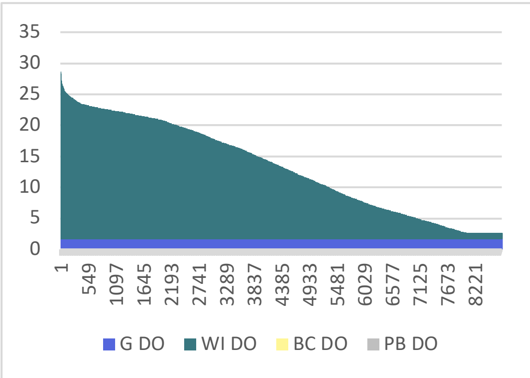
The eight figures below show the load-duration curves of the eight clusters in the Distributed scenario. The x-axis shows the hours per year, the y-axis the hourly production in MW.



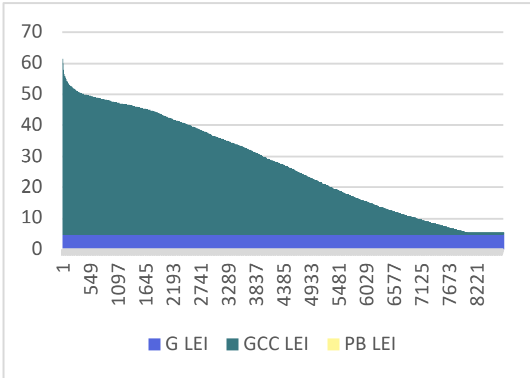
a) Load-duration curve Botlek for Distributed scenario



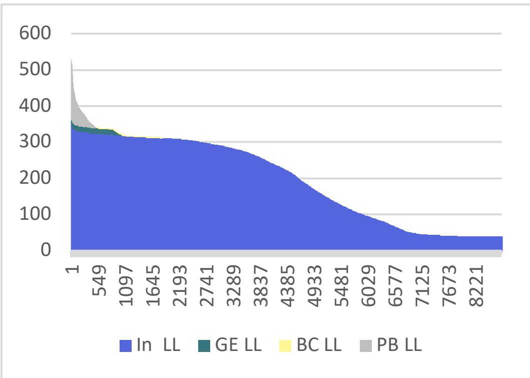
b) Load-duration curve The Hague for Distributed scenario



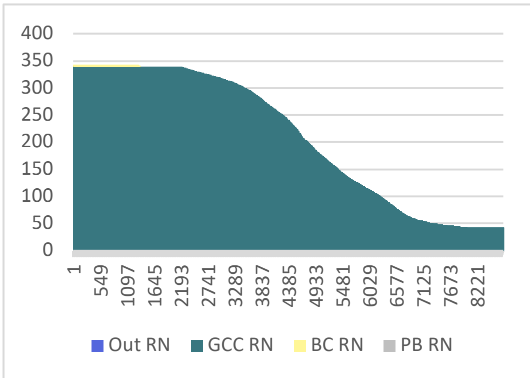
c) Load-duration curve Dordrecht for Distributed scenario



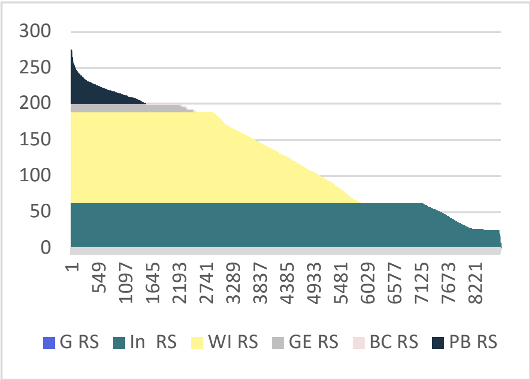
d) Load-duration curve Leiden for Distributed scenario



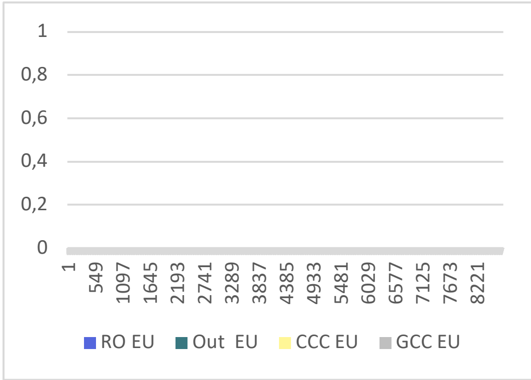
e) Load-duration curve Lansingerland for Distributed scenario



f) Load-duration curve Rotterdam North for Distributed scenario



g) Load-duration curve Rotterdam South for Distributed scenario

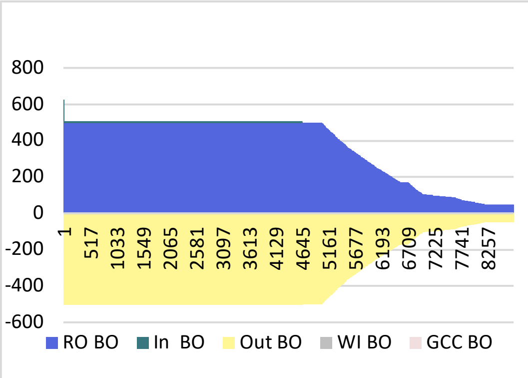


h) Load-duration curve Europort for Distributed scenario

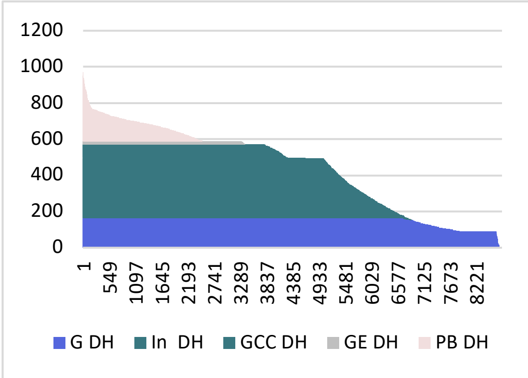
Figure 92 The load-duration curves of the eight clusters in the Distributed scenario

A.6.4.2 LIMITED

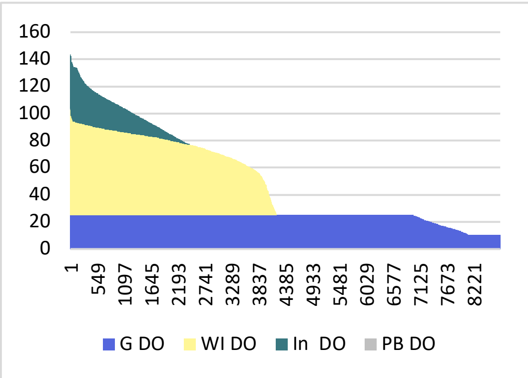
The 8 figures below show the load-duration curves of the eight clusters in the Unforeseen scenario. The x-axis shows the hours per year, the y-axis the hourly production in MW.



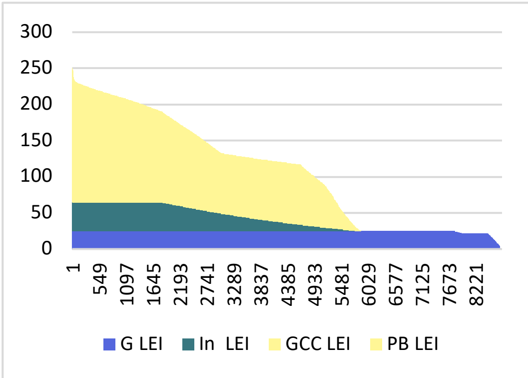
a) Load-duration curve Botlek for Limited scenario



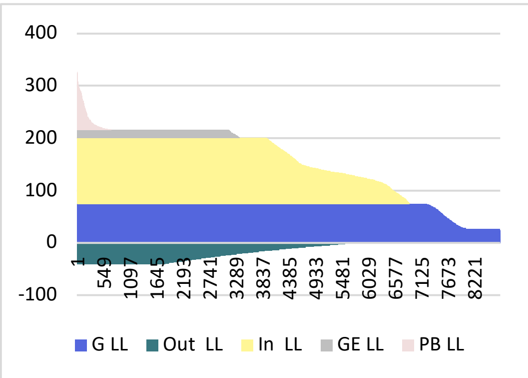
b) Load-duration curve The Hague for Limited scenario



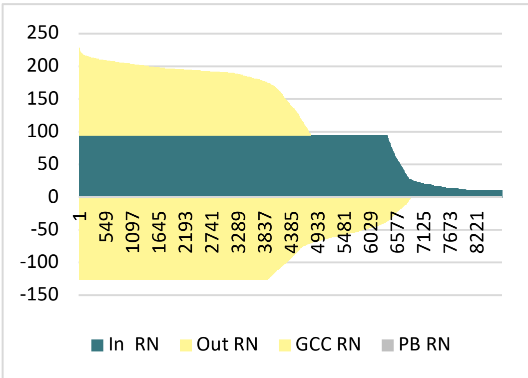
c) Load-duration curve Dordrecht for Limited scenario



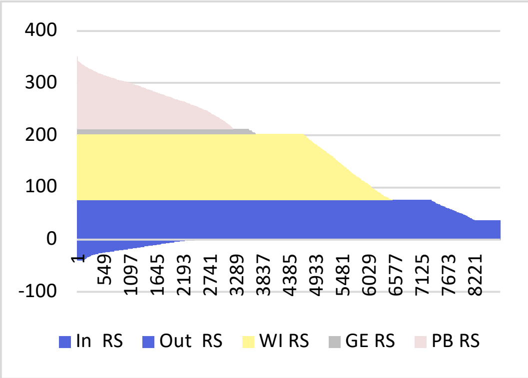
d) Load-duration curve Leiden for Limited scenario



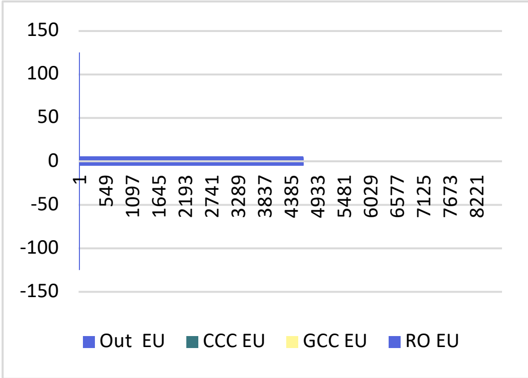
e) Load-duration curve Lansingerland for Limited scenario



f) Load-duration curve Rotterdam North for Limited scenario



g) Load-duration curve Rotterdam South for Limited scenario

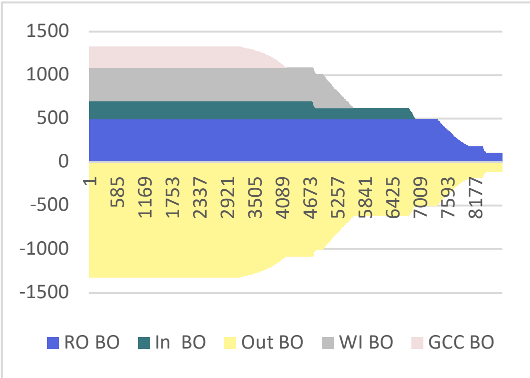


h) Load-duration curve Europort for Limited scenario

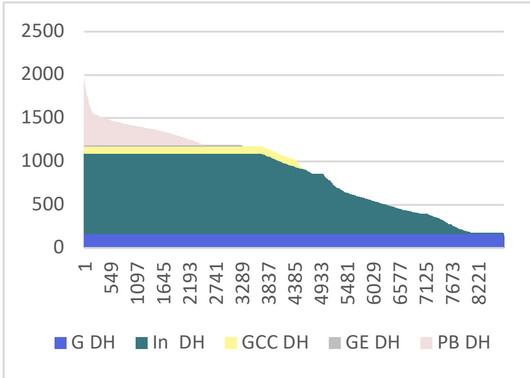
Figure 40 The load-duration curves of the eight clusters in the Limited scenario

A.6.4.3 UNFORESEEN

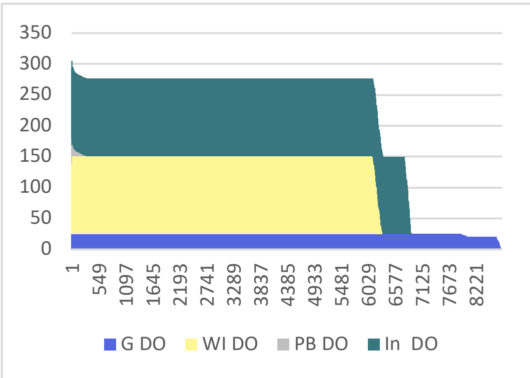
The 8 figures below show the load-duration curves of the eight clusters in the Unforeseen scenario. The x-axis shows the hours per year, the y-axis the hourly production in MW.



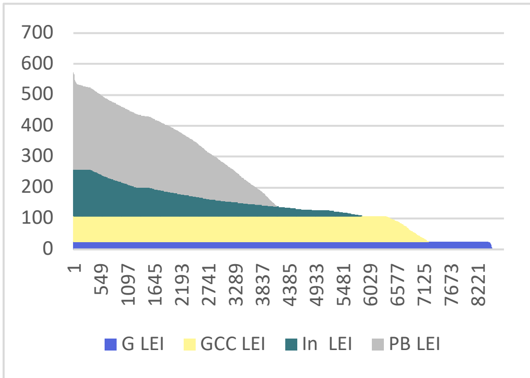
a) Load-duration curve Botlek for Unforeseen scenario



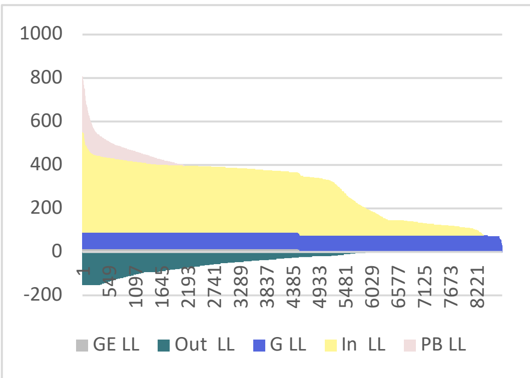
b) Load-duration curve The Hague for Unforeseen scenario



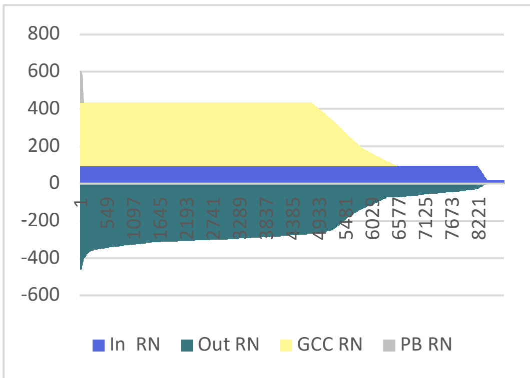
c) Load-duration curve Dordrecht for Unforeseen scenario



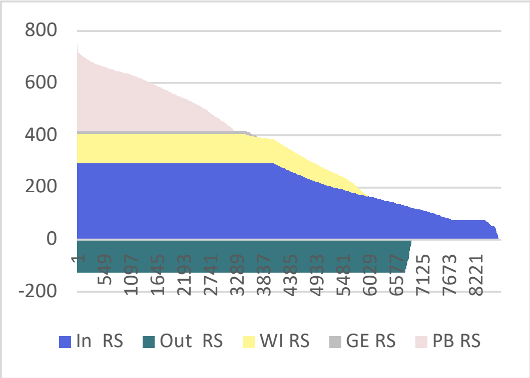
d) Load-duration curve Leiden for Unforeseen scenario



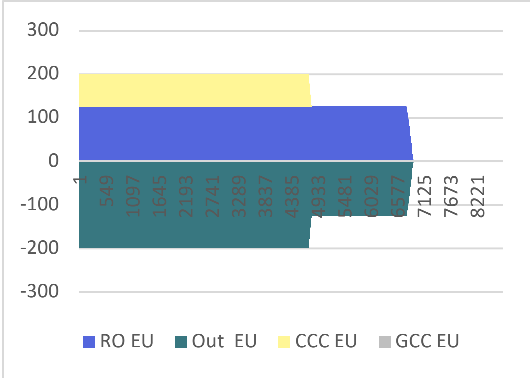
e) Load-duration curve Lansingerland for Unforeseen scenario



f) Load-duration curve Rotterdam North for Unforeseen scenario



g) Load-duration curve Rotterdam South for Unforeseen scenario

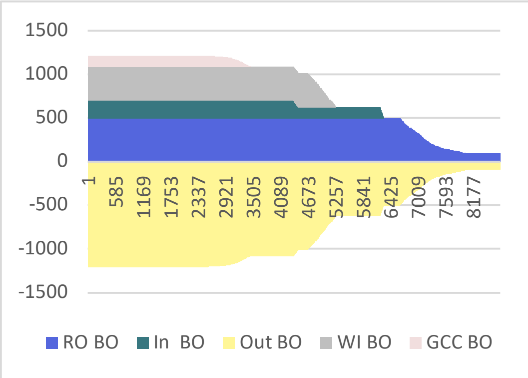


h) Load-duration curve Europort for Unforeseen scenario

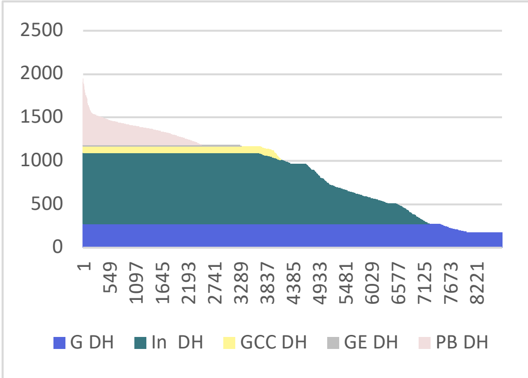
Figure 93 The load-duration curves of the eight clusters in the Unforeseen scenario

A.6.4.4 ABUNDANCE

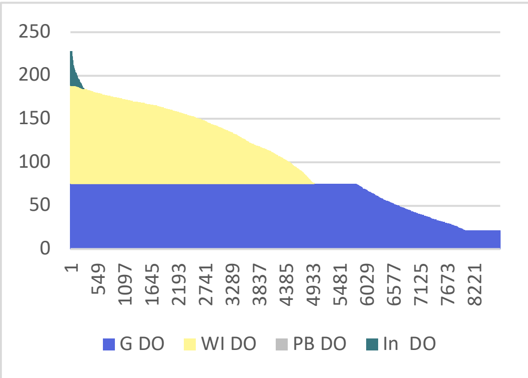
The 8 figures below show the load-duration curves of the eight clusters in the Abundance scenario. The x-axis shows the hours per year, the y-axis the hourly production in MW.



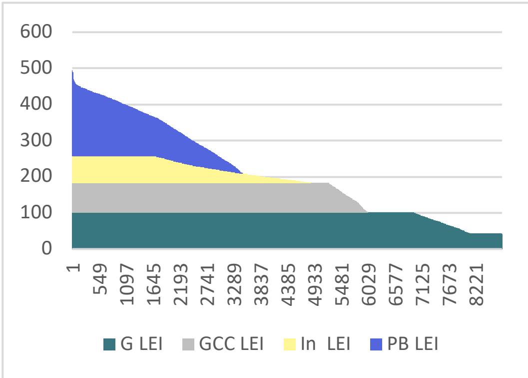
a) Load-duration curve Botlek for Abundance scenario



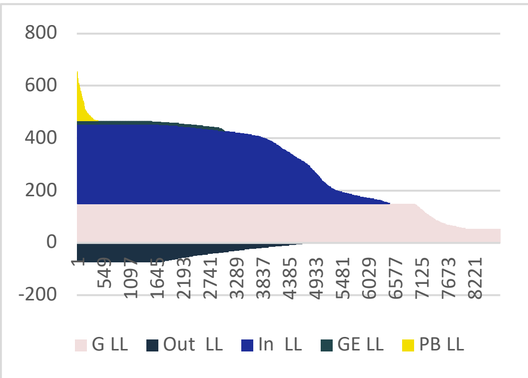
b) Load-duration curve The Hague for Abundance scenario



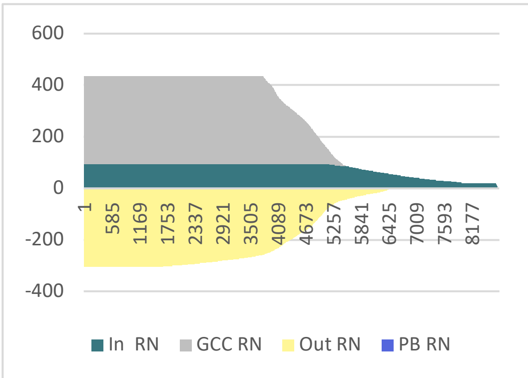
c) Load-duration curve Dordrecht for Abundance scenario



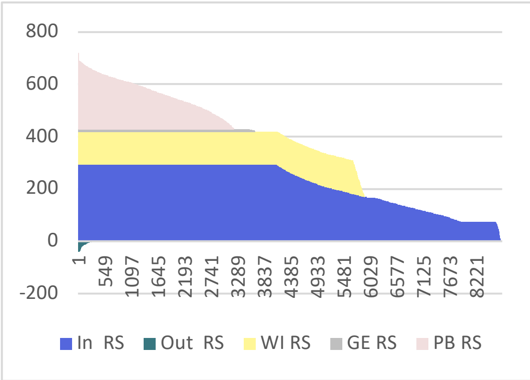
d) Load-duration curve Leiden for Abundance scenario



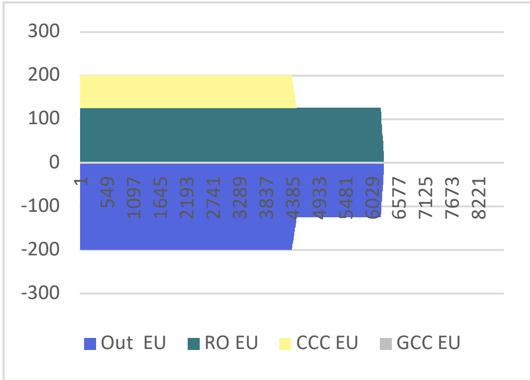
e) Load-duration curve Lansingerland for Abundance scenario



f) Load-duration curve Rotterdam North for Abundance scenario



g) Load-duration curve Rotterdam South for Abundance scenario



h) Load-duration curve Europort for Abundance scenario

Figure 94 The load-duration curves of the eight clusters in the Abundance scenario

APPENDIX 7: RESULTS STRUCTURED LITERATURE REVIEW

This appendix contains the overview of the structured literature review.

Table 70 Overview structured literature search

Concept	Database	Search term	Period	Results	Selection
Decision making on residential energy systems	Web of knowledge	"Individual " AND "decision making" AND "residential energy" AND "technology adoption" NOT "consumption" NOT "modelling"	2000-2018	1 article 1 review	Models of decision making and residential energy use By: Wilson, Charlie; Dowlatabadi, Hadi Year:2007 Context other article not relevant -> Case-study solar power in Texas
Participatory decision making	Web of knowledge	"Participatory decision making" and "design" and "process" and "government"	2000-2018	1 article (highly cited)	How does the context and design of participatory decision making processes affect their outcomes? Evidence from sustainable land management in global drylands By: de Vente, Joris; Reed, Mark S.; Stringer, Lindsay C.; et al Year: 2016
Collective learning and education for public support	Web of knowledge	"collective learning" and "education" and "public support"	2000-2018	0 articles	
	Web of knowledge	"collective learning" and "public support"		0 articles	
		Expert suggestion: Communities of practice			Communities of Practice and Social learning systems By: Etienne Wenger Year: 2000
Public support for energy policy	Web of knowledge	"public support" and "energy policy" and "transition"	2000-2018	2 articles	Both articles not relevant. Topic of public support for nuclear power stations Model study on market shares
	Web of knowledge	"public acceptability" and "energy policy" and "transition"	2000-2018	1 article	Public values for energy futures: Framing, indeterminacy and policy making By: Butler, C.; Demski, C.; Parkhill, K.; et al. Year: 2015

APPENDIX 8: INVITATION RESPONDENTS

The following invitation was distributed via:

- Seghwaert op Dreef, the local neighbourhood association
- De Spelevaert, the local primary school
- The local network of the researcher

Datum: 20-02-2018

Betreft: Uitnodiging bewonersonderzoek wonen zonder aardgas

Beste bewoner van de wijk Seghwaert,

De Rijksoverheid streeft er naar dat publieke gebouwen, huishoudens en (glastuinbouw-) bedrijven in Nederland in 2050 niet meer stoken en koken op aardgas. Dat betekent dat er tussen nu en 2050 elke week 4000 woningen van het aardgas af moeten gaan. Voor de wijk Seghwaert zijn nog geen concrete plannen om van het aardgas af te gaan, maar het Rijk en de gemeente Zoetermeer hebben wel de ambitie dat er ook in Seghwaert in 2050 geen aardgas meer gebruikt zal worden.

De gemeenten hebben van het Rijk de taak gekregen om wijk-voor-wijk de keuze voor een passend alternatief voor aardgas te faciliteren. De belangen en wensen van bewoners ten aanzien van wonen zonder aardgas zijn hierin van groot belang.

In opdracht van het Programmabureau Warmte Koude Zuid-Holland en in het kader van een afstudeeronderzoek aan de TU Delft voor de masteropleidingen Wetenschapscommunicatie en Technische Bestuurskunde, doe ik daarom onderzoek naar het perspectief van bewoners op aardgasloos wonen. Dit onderzoek gaat over:

1. de mening van bewoners over wonen zonder aardgas,
2. de gewenste organisatie van het besluitvormingsproces rondom keuze voor een passend alternatief voor aardgas in de buurt en
3. de informatiebehoefte van bewoners rondom aardgasloos wonen.

Voor dit onderzoek ben ik opzoek naar 20 bewoners van de wijk Seghwaert die hun mening over wonen zonder aardgas willen delen. Ik wil u dan ook van harte uitnodigen deel te nemen aan dit onderzoek.

Het onderzoek bestaat uit een interview waarin ik u aan de hand van open vragen en stellingen vraag naar uw mening over wonen zonder aardgas. Dit interview zal ongeveer 45 minuten duren en de resultaten zullen anoniem verwerkt worden.

Dit onderzoek heeft twee doelen. Het eerste doel is om de verschillende bewonersperspectieven op aardgasloos wonen binnen de wijk Seghwaert in kaart te brengen en terug te koppelen aan de gemeente Zoetermeer. Het tweede doel is om te bepalen of de gemeente aan de hand van deze informatie de keuze voor een passend alternatief voor aardgas zó kan faciliteren, dat deze aansluit bij de belangen en wensen van bewoners ten aanzien van wonen zonder aardgas.

Als u geïnteresseerd bent in deelname aan dit onderzoek, en/of in de onderzoeksresultaten, kunt u in de bijgevoegde lijst uw gegevens invullen. Of direct contact met mij opnemen via onderstaande informatie.

Met vriendelijke groet,

Eline van den Ende,

masterstudent Wetenschapscommunicatie en Technische Bestuurskunde, TU Delft

elinevandenende@gmail.com

+31624337715

APPENDIX 9: LIST OF STATEMENTS

The table below shows the list of statements used for the Q-methodological research.

Table 71 List of statements

	Category	Statement
1	Process – Timing	Technologische veranderingen gaan snel. Het is onzin om nu al na te denken over hoe mijn wijk of huis aardgasloos kan worden.
2	Process – Timing	Zelfs als de gemeente nog niet weet wat de oplossing voor aardgasloos wonen wordt, wil ik dat de gemeente me al vertelt dat mijn wijk van aardgas af gaat.
3	Process – Timing	Verhuizen is het juiste moment om je huis aardgasloos te maken.
4	Process – Phasing	In één keer aardgasvrij wonen kan niet. Je moet in kleine stapjes denken en zo snel mogelijk beginnen.
5	Process – Phasing	We zijn verslaafd aan fossiele brandstoffen. In plaats van jarenlange besluitvormingsprocessen moeten we gewoon 'cold-turkey' gaan. Wijken moeten in één keer van het gas af.
6	Process – Phasing	Als we in Nederland te snel, te grote stappen willen zetten op het gebied van aardgasloos wonen, struikelen we over onze eigen benen.
7	Process – self-efficacy	Ik weet onvoldoende van de alternatieven voor aardgas om daar een keuze over te kunnen maken.
8	Process – self-efficacy	Wonen zonder aardgas is ingewikkeld en ik weet niet hoe ik daar aan moet beginnen.
9	Process – self-efficacy	Ik kan zelf regelen dat mijn huis aardgasloos wordt.
10	Process – existing knowledge and perception	De aardbevingen in Groningen, de toenemende afhankelijkheid van Russisch gas, en/of het klimaatprobleem dwingen Nederland een andere weg in te slaan met betrekking tot haar energievoorziening.
11	Process – existing knowledge and perception	Aardgas is goedkoop, comfortabel en relatief schoon.
12	Process – political attitude	Aardgasloos wonen is weer zo'n plan dat iedereen door de strot geduwd wordt.
13	Process – political attitude	De afstand van Rijk tot wijk als het gaat om ambities voor aardgasloos wonen is te groot.
14	Process – political attitude	Wonen zonder aardgas is een linkse hobby.
15	Process – acceptance	Ik wil zekerheid over de impact van mijn investeringen voordat ik maatregelen neem om aardgasloos te gaan wonen.
16	Process – acceptance	Ik geloof niet dat mijn keuze om aardgasloos te gaan wonen veel impact heeft.
17	Process – acceptance	Het is belachelijk om te denken dat we zonder aardgas kunnen wonen.
18	Process – acceptance	Het is nodig dat we van het aardgas af gaan. Liever gisteren dan vandaag.
19	Content – improvement of quality of life	Algemene technische berekeningen over rendementen en kansen doen geen recht aan de impact van aardgasloos wonen op mijn leven.
20	Content – improvement of quality of life	De keuze voor een alternatief voor aardgas moet ook gaan over de impact van de nieuwe apparaten en bijkomende gedragsverandering op mijn leven.
21	Content – improvements of quality of life	Ik vindt het belangrijk dat de plannen voor aardgasloos wonen in mijn wijk flexibel blijven zodat toekomstige innovaties daarin kunnen worden opgenomen.
22	Content – improvements of quality of life	Als we de wijk moeten openbreken om de aardgasleiding te vervangen, dan biedt dat kansen om de wijk te verbeteren: groenvoorziening, bankjes, problematiek met hangjongeren, straatverlichting, eenzaamheid etc.
23	Content – improvements of quality of life	Aardgasloze woningen zijn comfortabeler dan woningen die nog met aardgas gestookt worden; beter geïsoleerd, constanter binnenklimaat, moderner etc.
24	Content – improvements of quality of life	Aardgasloos wonen zorgt voor een hoop rommel en gedoe, en uiteindelijk schiet ik er niks mee op.
25	Content – social justice and fairness	Door mijn huis te renoveren en aardgasloos te gaan wonen draag ik een steentje bij aan een betere leefomgeving en een groene, schone toekomst voor volgende generaties.
26	Content – social justice and fairness	Als aardgas wordt vervangen door een lokale energiebron dan levert dat economische kansen en werkgelegenheid op in mijn directe omgeving op.
27	Content – social justice and fairness	Ik wil het beste alternatief voor aardgas dat mogelijk is voor mijn woning. Zelfs als dat betekent dat daardoor niet de beste optie voor mijn wijk of regio gerealiseerd kan worden.
28	Content – social justice and fairness	Het is belangrijk dat energie toegankelijk blijft voor mensen met een laag inkomen. We moeten hen beschermen tegen hoge kosten.
29	Content – autonomy and power	Wokken en grillen op gas, de thermostaat een graadje hoger als ik het koud heb. Als ik dat wil, moet dat kunnen.
30	Content – autonomy and power	Het uitfaseren van aardgas biedt een kans om de afhankelijkheid van grote energiebedrijven te verminderen en de energievoorziening lokaal en eerlijker vorm te geven.
31	Content – safe, reliable and accessible	Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen.
32	Content – safe, reliable and accessible	Het grote voordeel van aardgasloos wonen is dat het veiliger is.
33	Content – safe, reliable and	Op de lange termijn zijn we voordeliger uit als we nu aardgasloos gaan wonen.

	accessible	
34	Content – safe, reliable and accessible	De alternatieven voor aardgas zijn voldoende ontwikkeld om in een veilige en betrouwbare warmtelevering te voorzien.
35	Content – protection of environment and nature	Als we aardgas gaan vervangen wil ik er zeker van zijn dat het alternatief de beste optie is voor het milieu is.
36	Process – level of participation	Als mijn wijk aan de beurt is, en alles is goed geregeld, dan wil ik best meegaan en overstappen op aardgasloos wonen. Maar ik wil er zelf zo min mogelijk tijd en moeite in steken.
37	Process – level of participation	Ik wil met professionals en ervaringsdeskundigen opties voor aardgasloos wonen kunnen bespreken.
38	Process – level of participation	Ik wil langs kunnen gaan bij iemand die aardgasloos woont. Hij of zij kan me dan veel vertellen over de verschillende maatregelen en ik kan meteen een kijkje nemen.
39	Process – level of participation	Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken.
40	Process – desired inclusion of stakeholders	Ik wil alleen van aardgas af als iedereen daar aan meedoet en meebetaalt, dus ook de industrie en het bedrijfsleven. De lasten moeten door iedereen gedragen worden en niet alleen bij de burger terecht komen.
41	Process – desired inclusion of stakeholders	Ik vind het belangrijk dat in gesprek kan gaan met mijn buren over de overgang naar een aardgasloze wijk.
42	Process – desired inclusion of stakeholders	Lokale energie initiatieven en wijk gebonden bewonersorganisaties moeten intensief betrokken worden in de besluitvorming over aardgasloos wonen op wijk niveau.
43	Process – desired inclusion of stakeholders	Ik voel mijzelf en mijn woonwensen over aardgasloos wonen door lokale energie initiatieven en wijk gebonden bewonersorganisaties goed vertegenwoordigd.
44	Process – stakeholder roles	Ik wil dat de gemeente mij als volwaardige gesprekpartner betrekt bij de besluitvorming over een aardgasloze wijk.
45	Process – stakeholder roles	Het is noodzakelijk dat gemeentes en de Provincie samenwerken om lokale en regionale plannen op elkaar af te stemmen.
46	Process – stakeholder roles	Het is aan de gemeente om woningbouw corporaties, installateurs, aannemers, lokale industrie, glastuinbouwers, woningeigenaren en bewoners te betrekken en het proces over aardgasloos wonen te (be)sturen.
47	Process – stakeholder roles	De gemeente moet mij ondersteunen in het keuzeproces over het vinden van het juiste alternatief voor aardgas.
48	Process – stakeholder roles	De gemeente heeft voldoende expertise om de transitie naar aardgasloos wonen in mijn wijk goed te begeleiden.
49	Process – stakeholder roles	Als de gemeente de opties voor aardgasloos wonen in mijn wijk in kaart heeft gebracht zonder dat met mij te overleggen, voel ik me gepasseerd.
50	Process – stakeholder roles	Om de transitie naar aardgasloos wonen te realiseren, moet de centrale overheid dit voor alle bewoners in de wijk verplichten.
51	Process – prospective outcome	Ik wil voor mijn eigen woning zelf een keuze kunnen maken over de vorm van aardgasloos wonen.
52	Process – prospective outcome	De gemeente mag bepalen wanneer ik en mijn medebewoners in mijn wijk van het aardgas afgaan.
53	Process – prospective outcome	De overgang naar aardgasloze wijken vraagt om collectieve en democratische beslissingen. Daar moeten alle wijkbewoners aan mee doen.
54	Process - prospective outcome	Wijkbewoners en de gemeente kunnen van elkaar leren als het gaat over aardgasloos wonen.
55	Process – prospective outcome	Een sociaal en gezellig proces is doorslaggevend om de veranderingen naar aardgasloos wonen door te kunnen zetten zonder het gevoel van thuis te verliezen.
56	Process – prospective outcome	De gemeente kan me helpen om de juiste specialisten te vinden en (indien nodig) vergunningen te regelen om aardgasloos te gaan wonen.
57	Process – prospective outcome	Alleen door subsidies en belastingvoordelen is het realiseren van een aardgasloze woning voor mij betaalbaar.
58	Process – prospective outcome	Ik heb behoefte aan een onafhankelijke organisatie, zoals een gemeenteloket, waar ik informatie kan inwinnen over aardgasloos wonen.

APPENDIX 10: FACTOR EXTRACTION

This appendix contains the outcome of the factor extraction.

A.10.1 CORRELATION MATRIX

The intercorrelation matrix displayed below shows the correlation between the respondents Q-sorts.

Table 72 Intercorrerlation matrix

	1_Res1	2_Res2	3_Res3	4_Res4	5_Res5	6_Res6	7_Res 7	8_Res8	9_Res9	10_Res8	11_Res11	12_Res12	13_Res13	14_Res14
1_Res1		-8	18	39	31	35	27	17	20	22	15	4	18	
2_Res2	-8		47	18	35	19	20	6	44	33	20	19	31	
3_Res3	18	47		35	36	34	44	27	21	55	23	18	1	
4_Res4	39	18	35		55	42	30	15	38	38	37	23	21	
5_Res5	31	35	36	55		50	35	42	34	53	46	-1	24	
6_Res6	35	19	34	42	50		29	27	29	36	29	14	30	
7_Res 7	27	20	44	30	35	29		10	22	48	30	27	10	
8_Res8	17	6	27	15	42	27	10		-7	29	28	-11	5	
9_Res9	20	44	21	38	34	29	22	-7		20	34	28	41	
10_Res8	22	33	55	38	53	36	48	29	20		30	-5	5	
11_Res11	15	20	23	37	46	29	30	28	34	30		0	27	
12_Res12	4	19	18	23	-1	14	27	-11	28	-5	0		27	
13_Res13	18	31	1	21	24	30	10	5	41	5	27	27		
14_Res14														

The correlation matrix shows that the following Q-sorts have a high (positive) correlation:

- 2 and 3
- 4,5 and 6
- 3 and 10
- 5 and 10
- 7 and 10

High correlations indicate that these respondents have similar viewpoints.

The correlation matrix also shows that the following Q-sets have a negative correlation:

- 1 and 2
- 8 and 9
- 10 and 12

Negative correlations indicate that these respondents have opposite viewpoints.

A.10.2 FACTOR EXTRACTION METHOD

There are two methods for factor extraction:

- centroid factor analysis
- principal components analysis (PCA)

PCA results in a single mathematically best solution which should (statistically) be accepted as the best explanation of the viewpoints. While centroid factor analysis results in several viewpoints, which can be further explored. The latter method is selected, as it allows for better exploration of the viewpoints based on the theoretical framework discussed in chapter 9.

A.10.3 NUMBER OF FACTORS

Each factor represents a viewpoint. Watts and Stenner (2012) discuss five methods to determine the number of factors.

3) The eigenvalues of the selected factors should be larger than 1.
4) In general, the maximum number of factors is 7.
5) A factor should have at least two or more significant factor loading Q-sorts.

   Significant factor loading = 2.58 x (1√No. of items in the Q-set).
   Significant factor loading = 2.58 x (1/√58) = 0,34
6) Hunphrey's rule: a factor is significant if the cross-product of its two highest loadings exceeds twice the standard error (Brown, 1980).

   Standard error = 1/√No. of items in the Q-set
   Standard error = 1/√58 = 0,13
7) Scree test

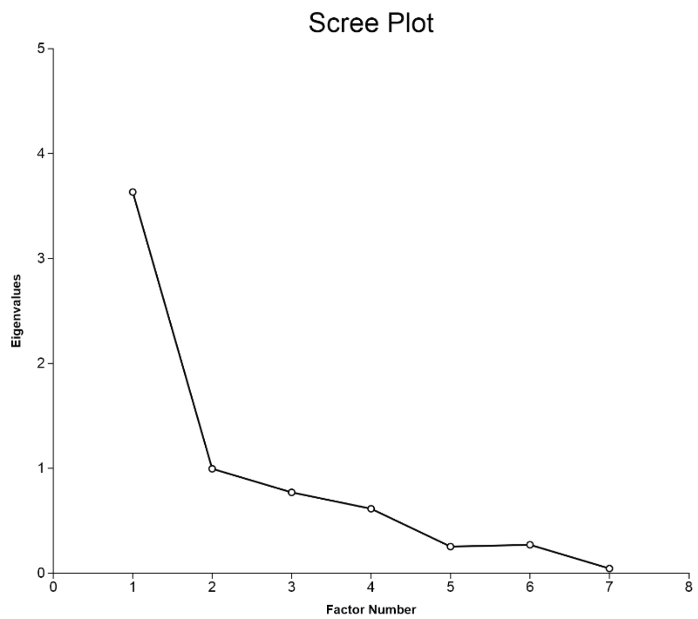


Figure 95 Scree plot

Besides this, the PQMethod software uses Horst's method to determine the number of factor extractions, based on the by Horst suggested limiting level of residual correlations.

The table hereafter shows the number of factors based on each of the methods discussed above.

Table 73 Overview of the number # of selected factors per method

Method	# of factors
Eigenvalues >1	1
Max. 7 factors	7
Two or more significant factor loading Q-sorts	5
Scree test	2
Horst's method	2

A.10.4 RESPONDENTS AND FACTORS

The table below shows which respondents correlate with which factors.

Table 74 Overview socio-economic characteristics respondents and perspectives

#	Age	Gender	Home ownership	Education level	Income level	Awareness transition	Sustainable home improvements	Factor
1	35	Male	Home owner	WO-master/Higher	Modal income	Yes	Yes	1
2	69	Female	Home owner – in AO	WO-master/Higher	Above modal income	Yes	Yes	
3	64	Male	Home owner	HAVO/VWO/MBO	Modal income	Yes	Yes	2
4	56	Female	Home owner	WO-master/Higher	Above modal income	Yes	Yes	1
5	52	Female	Tennant	HBO/WO-bachelor	Above modal income	Yes	No	1
6	56	Male	Home owner	HAVO/VWO/MBO	Above modal income	No	No	1
7	56	Male	Home owner	HBO/WO-bachelor	Above modal income	No	No	2
8	70	Male	Home owner	WO-master/Higher	Modal income	Yes	Yes	1
9	52	Male	Home owner	HAVO/VWO/MBO	Above modal income	Yes	No	3
10	25	Female	Tennant	HBO/WO-bachelor	Modal income	Yes	Yes	2
11	58	Male	Tennant	HBO/WO-bachelor	Above modal income	Yes	No	1
12	56	Male	Home owner	HBO/WO-bachelor	Above modal income	Yes	No	3
13	25	Female	Home owner – in AO	HBO/WO-bachelor	Modal income	No	No	3
14	76	Male	Home owner	WO-master/Higher	Above modal income	Yes	Yes	3

APPENDIX 11: CRIB SHEETS

The crib sheets are a way of ensuring that nothing obvious get missed or overlooked and it provides a wider system of organization of the interpretative process and encourages holism by forcing engagement with every item in a factor array (Watts & Stenner, 2012).

Hence, the following three tables contain the crib-sheets for factor 1, 2 and 4 each given in a separate table.

Table 75 Crib sheet statements in Factor 1

Highest Ranked Statements	**Factor 1**	**Consensus /Distinguishing**	**Factor 2**	**Factor 4**
34 De alternatieven voor aardgas zijn voldoende ontwikkeld om in een veilige en betrouwbare warmtelevering te voorzien.	6	D*	-1	-3
28 Het is belangrijk dat energie toegankelijk blijft voor mensen met een laag inkomen. We moeten hen beschermen tegen hoge kosten.	6	C*	3	4
Positive Statements Ranked Higher in Factor 1 Array than in Other Factor Arrays				
15 Ik wil zekerheid over de impact van mijn investeringen voordat ik maatregelen neem om aardgasloos te gaan wonen.	5		1	5
45 Het is noodzakelijk dat gemeentes en de Provincie samenwerken om lokale en regionale plannen op elkaar af te stemmen.	4	C	4	1
21 Ik vindt het belangrijk dat de plannen voor aardgasloos wonen in mijn wijk flexibel blijven zodat toekomstige innovaties daarin kunnen worden opgenomen.	3	C*	3	2
46 Het is aan de gemeente om woningbouw corporaties, installateurs, aannemers, lokale industrie, glastuinbouwers, woningeigenaren en bewoners te betrekken en het proces over aardgasloos wonen te (be)sturen.	3		0	2
52 De gemeente mag bepalen wanneer ik en mijn medebewoners in mijn wijk van het aardgas afgaan.	3	D	-5	0
47 De gemeente moet mij ondersteunen in het keuzeproces over het vinden van het juiste alternatief voor aardgas.	2	C*	1	2
32 Het grote voordeel van aardgasloos wonen is dat het veiliger is.	2		1	-3
50 Om de transitie naar aardgasloos wonen te realiseren, moet de centrale overheid dit voor alle bewoners in de wijk verplichten.	2		-3	0
54 Wijkbewoners en de gemeente kunnen van elkaar leren als het gaat over aardgasloos wonen.	2	C*	1	1
36 Als mijn wijk aan de beurt is, en alles is goed geregeld, dan wil ik best meegaan en overstappen op aardgasloos wonen. Maar ik wil er zelf zo min mogelijk tijd en moeite in steken.	2	C	1	-1
48 De gemeente heeft voldoende expertise om de transitie naar aardgasloos wonen in mijn wijk goed te begeleiden.	2	D	-1	-4
20 De keuze voor een alternatief voor aardgas moet ook gaan over de impact van de nieuwe apparaten en bijkomende gedragsverandering op mijn leven.	1		0	-1
33 Op de lange termijn zijn we voordeliger uit als we nu aardgasloos gaan wonen.	1		0	-2
56 De gemeente kan me helpen om de juiste specialisten te vinden en (indien nodig) vergunningen te regelen om aardgasloos te gaan wonen.	1	C*	0	0
16 Ik geloof niet dat mijn keuze om aardgasloos te gaan wonen veel impact heeft.	0	D	-4	-2
3 Verhuizen is het juiste moment om je huis aardgasloos te maken.	0	D*	-4	-6
Negative Statements Ranked Lower in Factor 1 Array than in Other Factor Arrays				
44 Ik wil dat de gemeente mij als volwaardige gesprekpartner betrekt bij de besluitvorming over een aardgasloze wijk.	0		3	1
39 Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken.	0	C*	0	2
31 Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen.	-1	C*	-1	1
4 In één keer aardgasvrij wonen kan niet. Je moet in kleine stapjes denken en zo snel mogelijk beginnen.	-1		1	3
37 Ik wil met professionals en ervaringsdeskundigen opties voor aardgasloos wonen kunnen bespreken.	-1	D	2	4
26 Als aardgas wordt vervangen door een lokale energiebron dan levert dat economische kansen en werkgelegenheid op in mijn directe omgeving op.	-1	C*	-1	0
51 Ik wil voor mijn eigen woning zelf een keuze kunnen maken over de vorm van aardgasloos wonen.	-1		4	0
11 Aardgas is goedkoop, comfortabel en relatief schoon.	-2		-2	1
53 De overgang naar aardgasloze wijken vraagt om collectieve en democratische beslissingen. Daar moeten alle wijkbewoners aan mee doen.	-2	D	1	2

19 Algemene technische berekeningen over rendementen en kansen doen geen recht aan de impact van aardgasloos wonen op mijn leven.	-2	C*	-2	-1
49 Als de gemeente de opties voor aardgasloos wonen in mijn wijk in kaart heeft gebracht zonder dat met mij te overleggen, voel ik me gepasseerd.	-2	D	3	1
38 Ik wil langs kunnen gaan bij iemand die aardgasloos woont. Hij of zij kan me dan veel vertellen over de verschillende maatregelen en ik kan meteen een kijkje nemen.	-2		3	-1
27 Ik wil het beste alternatief voor aardgas dat mogelijk is voor mijn woning. Zelfs als dat betekent dat daardoor niet de beste optie voor mijn wijk of regio gerealiseerd kan worden.	-3		-1	1
30 Het uitfaseren van aardgas biedt een kans om de afhankelijkheid van grote energiebedrijven te verminderen en de energievoorziening lokaal en eerlijker vorm te geven.	-3	C*	-2	-2
13 De afstand van Rijk tot wijk als het gaat om ambities voor aardgasloos wonen is te groot.	-3	D*	4	0
6 Als we in Nederland te snel, te grote stappen willen zetten op het gebied van aardgasloos wonen, struikelen we over onze eigen benen.	-3		-3	5
8 Wonen zonder aardgas is ingewikkeld en ik weet niet hoe ik daar aan moet beginnen.	-4	C	-4	-1
1 Technologische veranderingen gaan snel. Het is onzin om nu al na te denken over hoe mijn wijk of huis aardgasloos kan worden.	-4	D	-2	-3
14 Wonen zonder aardgas is een linkse hobby.	-5		-5	-2
Lowest Ranked Statements				
17 Het is belachelijk om te denken dat we zonder aardgas kunnen wonen.	-6		-6	-3
12 Aardgasloos wonen is weer zo'n plan dat iedereen door de strot geduwd wordt.	-6	D*	-3	-1

Table 76 Crib sheet statements in Factor 2

Highest Ranked Statements	**Factor 2**	**Consensus /Distinguishing**	**Factor 1**	**Factor 4**
25 Door mijn huis te renoveren en aardgasloos te gaan wonen draag ik een steentje bij aan een betere leefomgeving en een groene, schone toekomst voor volgende generaties.	6	D	3	2
2 Zelfs als de gemeente nog niet weet wat de oplossing voor aardgasloos wonen wordt, wil ik dat de gemeente me al vertelt dat mijn wijk van aardgas af gaat.	6		4	0
Positive Statements Ranked Higher in Factor 2 Array than in Other Factor Arrays				
22 Als we de wijk moeten openbreken om de aardgasleiding te vervangen, dan biedt dat kansen om de wijk te verbeteren: groenvoorziening, bankjes, problematiek met hangjongeren, straatverlichting, eenzaamheid etc.	5	D*	1	-2
35 Als we aardgas gaan vervangen wil ik er zeker van zijn dat het alternatief schoner de beste optie is voor het milieu is.	5	C*	3	3
13 De afstand van Rijk tot wijk als het gaat om ambities voor aardgasloos wonen is te groot.	4	D*	-3	0
51 Ik wil voor mijn eigen woning zelf een keuze kunnen maken over de vorm van aardgasloos wonen.	4	D*	-1	0
45 Het is noodzakelijk dat gemeentes en de Provincie samenwerken om lokale en regionale plannen op elkaar af te stemmen.	4	C	4	1
44 Ik wil dat de gemeente mij als volwaardige gesprekpartner betrekt bij de besluitvorming over een aardgasloze wijk.	3	D	0	1
21 Ik vindt het belangrijk dat de plannen voor aardgasloos wonen in mijn wijk flexibel blijven zodat toekomstige innovaties daarin kunnen worden opgenomen.	3	C*	3	2
38 Ik wil langs kunnen gaan bij iemand die aardgasloos woont. Hij of zij kan me dan veel vertellen over de verschillende maatregelen en ik kan meteen een kijkje nemen.	3	D*	-2	-1
49 Als de gemeente de opties voor aardgasloos wonen in mijn wijk in kaart heeft gebracht zonder dat met mij te overleggen, voel ik me gepasseerd.	3		-2	1
7 Ik weet onvoldoende van de alternatieven voor aardgas om daar een keuze over te kunnen maken.	2		0	-4
41 Ik vind het belangrijk dat in gesprek kan gaan met mijn buren over de overgang naar een aardgasloze wijk.	2	C*	1	0
58 Ik heb behoefte aan een onafhankelijke organisatie, zoals een gemeenteloket, waar ik informatie kan inwinnen over aardgasloos wonen.	2		1	-2
18 Het is nodig dat we van het aardgas af gaan. Liever gisteren dan vandaag.	2		0	-3
55 Een sociaal en gezellig proces is doorslaggevend om de veranderingen naar aardgasloos wonen door te kunnen zetten zonder het gevoel van thuis te verliezen.	0	D*	-4	-5
9 Ik kan zelf regelen dat mijn huis aardgasloos wordt.	0		-2	-5

Negative Statements Ranked Lower in Factor 2 Array than in Other Factor Arrays				
56 De gemeente kan me helpen om de juiste specialisten te vinden en (indien nodig) vergunningen te regelen om aardgasloos te gaan wonen.	0	C*	1	0
39 Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken.	0	C*	0	2
46 Het is aan de gemeente om woningbouw corporaties, installateurs, aannemers, lokale industrie, glastuinbouwers, woningeigenaren en bewoners te betrekken en het proces over aardgasloos wonen te (be)sturen.	0		3	2
40 Ik wil alleen van aardgas af als iedereen daar aan meedoet en meebetaalt, dus ook de industrie en het bedrijfsleven. De lasten moeten door iedereen gedragen worden en niet alleen bij de burger terecht komen.	0	D*	5	6
57 Alleen door subsidies en belastingvoordelen is het realiseren van een aardgasloze woning voor mij betaalbaar.	-1		0	3
10 De aardbevingen in Groningen, de toenemende afhankelijkheid van Russisch gas, en/of het klimaatprobleem dwingen Nederland een andere weg in te slaan met betrekking tot haar energievoorziening.	-1	D*	4	6
31 Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen.	-1	C*	-1	1
26 Als aardgas wordt vervangen door een lokale energiebron dan levert dat economische kansen en werkgelegenheid op in mijn directe omgeving op.	-1	C*	-1	0
43 Ik voel mijzelf en mijn woonwensen over aardgasloos wonen door lokale energie initiatieven en wijk gebonden bewonersorganisaties goed vertegenwoordigd.	-2	C*	-1	-1
19 Algemene technische berekeningen over rendementen en kansen doen geen recht aan de impact van aardgasloos wonen op mijn leven.	-2	C*	-2	-1
11 Aardgas is goedkoop, comfortabel en relatief schoon.	-2		-2	1
29 Wokken en grillen op gas, de thermostaat een graadje hoger als ik het koud heb. Als ik dat wil, moet dat kunnen.	-3	D	0	4
23 Aardgasloze woningen zijn comfortabeler dan woningen die nog met aardgas gestookt worden; beter geïsoleerd, constanter binnenklimaat, moderner etc.	-3		-1	3
6 Als we in Nederland te snel, te grote stappen willen zetten op het gebied van aardgasloos wonen, struikelen we over onze eigen benen.	-3		-3	5
50 Om de transitie naar aardgasloos wonen te realiseren, moet de centrale overheid dit voor alle bewoners in de wijk verplichten.	-3	D*	2	0
16 Ik geloof niet dat mijn keuze om aardgasloos te gaan wonen veel impact heeft.	-4		0	-2
8 Wonen zonder aardgas is ingewikkeld en ik weet niet hoe ik daar aan moet beginnen.	-4	C	-4	-1
14 Wonen zonder aardgas is een linkse hobby.	-5		-5	-2
52 De gemeente mag bepalen wanneer ik en mijn medebewoners in mijn wijk van het aardgas afgaan.	-5	D*	3	0
Lowest Ranked Statements				
24 Aardgasloos wonen zorgt voor een hoop rommel en gedoe, en uiteindelijk schiet ik er niks mee op.	-6	C*	-5	-4
17 Het is belachelijk om te denken dat we zonder aardgas kunnen wonen.	-6		-6	-3

Table 77 Crib sheet statements in Factor 4

Highest Ranked Statements	**Factor 4**	**Distinguishing**	**Factor 1**	**Factor 2**
40 Ik wil alleen van aardgas af als iedereen daar aan meedoet en meebetaalt, dus ook de industrie en het bedrijfsleven. De lasten moeten door iedereen gedragen worden en niet alleen bij de burger terecht komen.	6		5	0
10 De aardbevingen in Groningen, de toenemende afhankelijkheid van Russisch gas, en/of het klimaatprobleem dwingen Nederland een andere weg in te slaan met betrekking tot haar energievoorziening.	6		4	-1
Positive Statements Ranked Higher in Factor 4 Array than in Other Factor Arrays				
15 Ik wil zekerheid over de impact van mijn investeringen voordat ik maatregelen neem om aardgasloos te gaan wonen.	5		5	1
6 Als we in Nederland te snel, te grote stappen willen zetten op het gebied van aardgasloos wonen, struikelen we over onze eigen benen.	5	D*	-3	-3
29 Wokken en grillen op gas, de thermostaat een graadje hoger als ik het koud heb. Als ik dat wil, moet dat kunnen.	4	D*	0	-3
37 Ik wil met professionals en ervaringsdeskundigen opties voor aardgasloos wonen kunnen bespreken.	4		-1	2
57 Alleen door subsidies en belastingvoordelen is het realiseren van een aardgasloze woning voor mij betaalbaar.	3	D*	0	-1
4 In één keer aardgasvrij wonen kan niet. Je moet in kleine stapjes denken en zo snel mogelijk beginnen.	3		-1	1
23 Aardgasloze woningen zijn comfortabeler dan woningen die nog met aardgas gestookt worden; beter geïsoleerd, constanter binnenklimaat, moderner etc.	3	D*	-1	-3
42 Lokale energie initiatieven en wijk gebonden bewonersorganisaties moeten intensief betrokken worden in de besluitvorming over aardgasloos wonen op wijk niveau.	3	C*	1	2
47 De gemeente moet mij ondersteunen in het keuzeproces over het vinden van het juiste alternatief voor aardgas.	2	C*	2	1
53 De overgang naar aardgasloze wijken vraagt om collectieve en democratische beslissingen. Daar moeten alle wijkbewoners aan mee doen.	2		-2	1
39 Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken.	2	C*	0	0
11 Aardgas is goedkoop, comfortabel en relatief schoon.	1	D	-2	-2
27 Ik wil het beste alternatief voor aardgas dat mogelijk is voor mijn woning. Zelfs als dat betekent dat daardoor niet de beste optie voor mijn wijk of regio gerealiseerd kan worden.	1		-3	-1
31 Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen.	1	C*	-1	-1
26 Als aardgas wordt vervangen door een lokale energiebron dan levert dat economische kansen en werkgelegenheid op in mijn directe omgeving op.	0	C*	-1	-1
Negative Statements Ranked Lower in Factor 4 Array than in Other Factor Arrays				
56 De gemeente kan me helpen om de juiste specialisten te vinden en (indien nodig) vergunningen te regelen om aardgasloos te gaan wonen.	0	C*	1	0
2 Zelfs als de gemeente nog niet weet wat de oplossing voor aardgasloos wonen wordt, wil ik dat de gemeente me al vertelt dat mijn wijk van aardgas af gaat.	0	D*	4	6
41 Ik vind het belangrijk dat in gesprek kan gaan met mijn buren over de overgang naar een aardgasloze wijk.	0	C*	1	2
36 Als mijn wijk aan de beurt is, en alles is goed geregeld, dan wil ik best meegaan en overstappen op aardgasloos wonen. Maar ik wil er zelf zo min mogelijk tijd en moeite in steken.	-1	C	2	1
20 De keuze voor een alternatief voor aardgas moet ook gaan over de impact van de nieuwe apparaten en bijkomende gedragsverandering op mijn leven.	-1		1	0
22 Als we de wijk moeten openbreken om de aardgasleiding te vervangen, dan biedt dat kansen om de wijk te verbeteren: groenvoorziening, bankjes, problematiek met hangjongeren, straatverlichting, eenzaamheid etc.	-2	D*	1	5
58 Ik heb behoefte aan een onafhankelijke organisatie, zoals een gemeenteloket, waar ik informatie kan inwinnen over aardgasloos wonen.	-2	D*	1	2
33 Op de lange termijn zijn we voordeliger uit als we nu aardgasloos gaan wonen.	-2	D	1	0
32 Het grote voordeel van aardgasloos wonen is dat het veiliger is.	-3	D*	2	1
34 De alternatieven voor aardgas zijn voldoende ontwikkeld om in een veilige en betrouwbare warmtelevering te voorzien.	-3	D	6	-1
18 Het is nodig dat we van het aardgas af gaan. Liever gisteren dan vandaag.	-3	D*	0	2
48 De gemeente heeft voldoende expertise om de transitie naar aardgasloos wonen in mijn wijk goed te begeleiden.	-4	D	2	-1
7 Ik weet onvoldoende van de alternatieven voor aardgas om daar een keuze over te kunnen	-4	D*	0	2

maken.				
55 Een sociaal en gezellig proces is doorslaggevend om de veranderingen naar aardgasloos wonen door te kunnen zetten zonder het gevoel van thuis te verliezen.	-5		-4	0
9 Ik kan zelf regelen dat mijn huis aardgasloos wordt.	-5	D*	-2	0
Lowest Ranked Statements				
3 Verhuizen is het juiste moment om je huis aardgasloos te maken.	-6		0	-4
5 We zijn verslaafd aan fossiele brandstoffen. In plaats van jarenlange besluitvormingsprocessen moeten we gewoon 'cold-turkey' gaan. Wijken moeten in één keer van het gas af.	-6	D*	-3	-2

APPENDIX 12: FACTOR SCORES

The following table shows the factor scores per statement. The statements are sorted from most distinguishing to most consensus.

Table 78 Factor scores per statement, sorted from most distinguishing to most consensus

Statement	Factor 1	Factor 2	Factor 4	Z-Score Variance	meaning
52 De gemeente mag bepalen wanneer ik en mijn medebewoners in mijn wijk van het aardgas afgaan.	3	-5	0	1,461	Process – prospective outcome
34 De alternatieven voor aardgas zijn voldoende ontwikkeld om in een veilige en betrouwbare warmtelevering te voorzien.	6	-1	-3	1,326	Content – safe, reliable and accessible
6 Als we in Nederland te snel, te grote stappen willen zetten op het gebied van aardgasloos wonen, struikelen we over onze eigen benen.	-3	-3	5	1,287	Process – Phasing
40 Ik wil alleen van aardgas af als iedereen daar aan meedoet en meebetaalt, dus ook de industrie en het bedrijfsleven. De lasten moeten door iedereen gedragen worden en niet alleen bij de burger terecht komen.	5	0	6	0,95	Process – desired inclusion of stakeholders
12 Aardgasloos wonen is weer zo'n plan dat iedereen door de strot geduwd wordt.	-6	-3	-1	0,946	Process – political attitude
13 De afstand van Rijk tot wijk als het gaat om ambities voor aardgasloos wonen is te groot.	-3	4	0	0,915	Process – political attitude
22 Als we de wijk moeten openbreken om de aardgasleiding te vervangen, dan biedt dat kansen om de wijk te verbeteren: groenvoorziening, bankjes, problematiek met hangjongeren, straatverlichting, eenzaamheid etc.	1	5	-2	0,909	Content – improvements of quality of life
29 Wokken en grillen op gas, de thermostaat een graadje hoger als ik het koud heb. Als ik dat wil, moet dat kunnen.	0	-3	4	0,861	Content – autonomy and power
10 De aardbevingen in Groningen, de toenemende afhankelijkheid van Russisch gas, en/of het klimaatprobleem dwingen Nederland een andere weg in te slaan met betrekking tot haar energievoorziening.	4	-1	6	0,832	Process – existing knowledge and perception
7 Ik weet onvoldoende van de alternatieven voor aardgas om daar een keuze over te kunnen maken.	0	2	-4	0,805	Process – self-efficacy
38 Ik wil langs kunnen gaan bij iemand die aardgasloos woont. Hij of zij kan me dan veel vertellen over de verschillende maatregelen en ik kan meteen een kijkje nemen.	-2	3	-1	0,685	Process – level of participation
50 Om de transitie naar aardgasloos wonen te realiseren, moet de centrale overheid dit voor alle bewoners in de wijk verplichten.	2	-3	0	0,592	Process – stakeholder roles
3 Verhuizen is het juiste moment om je huis aardgasloos te maken.	0	-4	-6	0,587	Process – Timing
55 Een sociaal en gezellig proces is doorslaggevend om de veranderingen naar aardgasloos wonen door te kunnen zetten zonder het gevoel van thuis te verliezen.	-4	0	-5	0,566	Process – prospective outcome
2 Zelfs als de gemeente nog niet weet wat de oplossing voor aardgasloos wonen wordt, wil ik dat de gemeente me al vertelt dat mijn wijk van aardgas af gaat.	4	6	0	0,562	Process – Timing
23 Aardgasloze woningen zijn comfortabeler dan woningen die nog met aardgas gestookt worden; beter geïsoleerd, constanter binnenklimaat, moderner etc.	-1	-3	3	0,546	Content – improvements of quality of life
32 Het grote voordeel van aardgasloos wonen is dat het veiliger is.	2	1	-3	0,526	Content – safe, reliable and accessible
51 Ik wil voor mijn eigen woning zelf een keuze kunnen maken over de vorm van aardgasloos wonen.	-1	4	0	0,513	Process – prospective outcome
18 Het is nodig dat we van het aardgas af gaan. Liever gisteren dan vandaag.	0	2	-3	0,455	Process – acceptance
48 De gemeente heeft voldoende expertise om de transitie naar aardgasloos wonen in mijn wijk goed te begeleiden.	2	-1	-4	0,449	Process – stakeholder

					roles
15 Ik wil zekerheid over de impact van mijn investeringen voordat ik maatregelen neem om aardgasloos te gaan wonen.	5	1	5	0,443	Process – acceptance
9 Ik kan zelf regelen dat mijn huis aardgasloos wordt.	-2	0	-5	0,433	Process – self-efficacy
49 Als de gemeente de opties voor aardgasloos wonen in mijn wijk in kaart heeft gebracht zonder dat met mij te overleggen, voel ik me gepasseerd.	-2	3	1	0,405	Process – stakeholder roles
37 Ik wil met professionals en ervaringsdeskundigen opties voor aardgasloos wonen kunnen bespreken.	-1	2	4	0,401	Process – level of participation
58 Ik heb behoefte aan een onafhankelijke organisatie, zoals een gemeenteloket, waar ik informatie kan inwinnen over aardgasloos wonen.	1	2	-2	0,382	Process – prospective outcome
5 We zijn verslaafd aan fossiele brandstoffen. In plaats van jarenlange besluitvormingsprocessen moeten we gewoon 'cold-turkey' gaan. Wijken moeten in één keer van het gas af.	-3	-2	-6	0,345	Process – Phasing
16 Ik geloof niet dat mijn keuze om aardgasloos te gaan wonen veel impact heeft.	0	-4	-2	0,334	Process – acceptance
17 Het is belachelijk om te denken dat we zonder aardgas kunnen wonen.	-6	-6	-3	0,328	Process – acceptance
4 In één keer aardgasvrij wonen kan niet. Je moet in kleine stapjes denken en zo snel mogelijk beginnen.	-1	1	3	0,308	Process – Phasing
57 Alleen door subsidies en belastingvoordelen is het realiseren van een aardgasloze woning voor mij betaalbaar.	0	-1	3	0,296	Process – prospective outcome
33 Op de lange termijn zijn we voordeliger uit als we nu aardgasloos gaan wonen.	1	0	-2	0,264	Content – safe, reliable and accessible
14 Wonen zonder aardgas is een linkse hobby.	-5	-5	-2	0,263	Process – political attitude
25 Door mijn huis te renoveren en aardgasloos te gaan wonen draag ik een steentje bij aan een betere leefomgeving en een groene, schone toekomst voor volgende generaties.	3	6	2	0,263	Content – social justice and fairness
11 Aardgas is goedkoop, comfortabel en relatief schoon.	-2	-2	1	0,249	Process – existing knowledge and perception
44 Ik wil dat de gemeente mij als volwaardige gesprekpartner betrekt bij de besluitvorming over een aardgasloze wijk.	0	3	1	0,239	Process – stakeholder roles
53 De overgang naar aardgasloze wijken vraagt om collectieve en democratische beslissingen. Daar moeten alle wijkbewoners aan mee doen.	-2	1	2	0,229	Process – prospective outcome
46 Het is aan de gemeente om woningbouw corporaties, installateurs, aannemers, lokale industrie, glastuinbouwers, woningeigenaren en bewoners te betrekken en het proces over aardgasloos wonen te (be)sturen.	3	0	2	0,223	Process – stakeholder roles
1 Technologische veranderingen gaan snel. Het is onzin om nu al na te denken over hoe mijn wijk of huis aardgasloos kan worden.	-4	-2	-3	0,189	Process – Timing
27 Ik wil het beste alternatief voor aardgas dat mogelijk is voor mijn woning. Zelfs als dat betekent dat daardoor niet de beste optie voor mijn wijk of regio gerealiseerd kan worden.	-3	-1	1	0,188	Content – social justice and fairness
20 De keuze voor een alternatief voor aardgas moet ook gaan over de impact van de nieuwe apparaten en bijkomende gedragsverandering op mijn leven.	1	0	-1	0,182	Content – improvement of quality of life
8 Wonen zonder aardgas is ingewikkeld en ik weet niet hoe ik daar aan moet beginnen.	-4	-4	-1	0,146	Process – self-efficacy
36 Als mijn wijk aan de beurt is, en alles is goed geregeld, dan wil ik best meegaan en overstappen op aardgasloos wonen. Maar ik wil er zelf zo min mogelijk tijd en moeite in steken.	2	1	-1	0,132	Process – level of participation
24 Aardgasloos wonen zorgt voor een hoop rommel en gedoe, en uiteindelijk schiet ik er niks mee op.	-5	-6	-4	0,123	Content – improvements of quality of life
45 Het is noodzakelijk dat gemeentes en de Provincie samenwerken om lokale en regionale plannen op elkaar af te stemmen.	4	4	1	0,112	Process – stakeholder roles
41 Ik vind het belangrijk dat in gesprek kan gaan met mijn buren over de overgang naar een aardgasloze wijk.	1	2	0	0,09	Process – desired

					inclusion of stakeholders
35 Als we aardgas gaan vervangen wil ik er zeker van zijn dat het alternatide beste optie is voor het milieu is.	3	5	3	0,08	Content – protection of environment and nature
28 Het is belangrijk dat energie toegankelijk blijft voor mensen met een laag inkomen. We moeten hen beschermen tegen hoge kosten.	6	3	4	0,075	Content – social justice and fairness
39 Aardgasloos wonen staat niet boven aan mijn prioriteitenlijst. Ik besteed mijn tijd en geld liever aan andere zaken.	0	0	2	0,065	Process – level of participation
42 Lokale energie initiatieven en wijk gebonden bewonersorganisaties moeten intensief betrokken worden in de besluitvorming over aardgasloos wonen op wijk niveau.	1	2	3	0,059	Process – desired inclusion of stakeholders
31 Ik wil als gevolg van aardgasloos wonen vooral niet zelf moeten investeren in mijn woning of straks duurder uit zijn voor mijn energierekening. Dat kan of wil ik niet betalen.	-1	-1	1	0,054	Content – safe, reliable and accessible
54 Wijkbewoners en de gemeente kunnen van elkaar leren als het gaat over aardgasloos wonen.	2	1	1	0,043	Process - prospective outcome
47 De gemeente moet mij ondersteunen in het keuzeproces over het vinden van het juiste alternatief voor aardgas.	2	1	2	0,034	Process – stakeholder roles
30 Het uitfaseren van aardgas biedt een kans om de afhankelijkheid van grote energiebedrijven te verminderen en de energievoorziening lokaal en eerlijker vorm te geven.	-3	-2	-2	0,025	Content – autonomy and power
21 Ik vindt het belangrijk dat de plannen voor aardgasloos wonen in mijn wijk flexibel blijven zodat toekomstige innovaties daarin kunnen worden opgenomen.	3	3	2	0,018	Content – improvements of quality of life
43 Ik voel mijzelf en mijn woonwensen over aardgasloos wonen door lokale energie initiatieven en wijk gebonden bewonersorganisaties goed vertegenwoordigd.	-1	-2	-1	0,018	Process – desired inclusion of stakeholders
26 Als aardgas wordt vervangen door een lokale energiebron dan levert dat economische kansen en werkgelegenheid op in mijn directe omgeving op.	-1	-1	0	0,015	Content – social justice and fairness
56 De gemeente kan me helpen om de juiste specialisten te vinden en (indien nodig) vergunningen te regelen om aardgasloos te gaan wonen.	1	0	0	0,005	Process – prospective outcome
19 Algemene technische berekeningen over rendementen en kansen doen geen recht aan de impact van aardgasloos wonen op mijn leven.	-2	-2	-1	0	Content – improvement of quality of life

APPENDIX 13: ANSWERS TO DISCUSSION QUESTIONS FOCUS GROUP

There was consensus among the participants about the answers to all of the questions. Therefore, the answers are formulated as one answer. The audio file of the focus group is available upon request.

- *What is your current communication approach with regard to the phase-out of natural gas?*

We are currently exploring how we can organize our communication process. To design this process, we are looking at neighbouring municipalities (Woerden and Utrecht) to see what communication-actions they use and how people respond to this. We are struggling with the moment at which we should start to communicate. In Utrecht, they communicate as early as possible. To raise awareness of the transition and to make sure that people are able to make the right decision in the process of making their house gas-free. For example, when purchasing a new kitchen. We have not really started communicating yet. However, especially towards individual homeowners we want to start communicating soon. For this very reason that they can then avoid making decisions that will make them dependent on natural gas longer than necessary.

We have a “blok-voor-blok” communication approach in collaboration with DeZo, the local energy cooperation in Zoetermeer, and Reimarkt, which is company that offers products aimed at sustainable home improvements. The municipality subsidizes DeZo and Reimarkt. This communications approach is aimed at sustainable living, and not necessarily only at the phase-out of natural gas. However, this approach does raise awareness about the transition at hand. This approach is aimed at home-owners.

Housing associations will take-up the largest part of the communication towards tenants. Also because 70% of the tenants, need to agree with large-scale renovations, like the ones necessary for the phase-out of natural gas. These large-scale renovations will most likely coincide with a new financial structure (energy-performance based billing). Tenants have to agree with these changes. Housing associations have a very intense communication-trajectory, with individual conversations. These conversations mainly focus on the financial concepts of the transition.

For individual homeowners, we currently do not really have an alternative for natural gas to offer. There is no nearby district heating network, which they can easily be connected to. Therefore, we need to explore which options there are for individual homeowners, and which options are financially feasible. We would like to present individual home-owners with a set of alternatives.

- *What do you currently know about residents’ needs with regard to the transition? In addition, how does this approach currently relate to these needs?*

Recently a report on four types of lifestyles within Zoetermeer was presented. The research indicates four different lifestyles, typed as: vitality, control, harmony and protection. This data is a nice starting point for designing communication. However, the types do not relate specifically to the phase-out of natural gas. In that sense, we have little insight in what residents expect from us in this transition.

- *Can resident perspectives, like the ones presented today, support the municipality Zoetermeer in the development of a communication approach with regard to the phase-out of natural gas?*
- *What is the added value of the resident perspectives as presented today?*

We are very happy with these perspectives. They are well structured and recognizable. The content of the perspectives provides a basis on which the right communication means can be selected or we can use these perspectives to check if our communication approach fits with the different perspectives.

In particular, it is interesting to see that early-communication is highly valued in all three perspectives, but also that the perspectives provide some insights in what it means to communicate “early”. We are currently struggling with defining the right moment to start communicating and this is very insightful.

- *How can these resident perspectives be further improved?*

It would be helpful if the perspectives were complete, and valid for the whole municipality or in particular in Palenstein, as we are currently focussing on this district. Moreover, it would be helpful if we knew which perspectives are dominant in which district, or amongst which group of residents. Then we could tailor our communication approach to these groups. For example, it would be nice if the perspectives could be linked to the research mentioned earlier. Because we already know so-much about differences in resident groups.

- *What is currently the relation between communication and decision-making with regard to the phase-out of natural gas?*

There is no direct link. Except from that, individual homeowners and tenants both have a say in the selection of an alternative for natural gas, as explained for the first question.

- *What is currently the approach of the municipality Zoetermeer in the phase out of natural gas?*

Currently, Zoetermeer focusses on BENG and NOM concepts. The plans of the Province of South Holland to realize a large heat infrastructure do not directly apply to Zoetermeer, as the pipelines will initially be at quite a large distance of Zoetermeer. Besides this, there are only very limited options for realizing a district heating system in Zoetermeer without access to this pipeline, as there are no real options for residual heat or geothermal heat available.

BENG (bijna energie neutraal) concepts aim at realizing a house that is nearly energy-neutral. BENG is applied in the existing built environment. At the moment these concepts are only applied for houses owned by housing associations. Renovation to a BENG home is part of planned large-scale renovations. To accomplish a BENG house, large-scale renovations are necessary. NOM (nul-op-de-meter) concepts are newly build houses that are energy-neutral.

We don't really have a approach yet for individual homeowners. We are in the process of investigating options, and we are really still looking for attractive propositions for individual homeowners and they are difficult to find. For example, we are exploring if individual homeowners are also interested in BENG concepts and the connected new energy billing system.

- *To what extent can insights in the residents needs with regard to this process influence this approach?*

We are in the process of investigating options for especially the group of individual homeowners. We are exploring all options. We do not know what the right time is to communicate these options and how we should present them. These perspectives provide insights in when people would like to be engaged in this process. In addition, how they would like to be engaged or represented. In that sense, the perspectives support us in the process.

In addition, the fact that some perspectives indicate that people are willing to comply with collective solutions, rather than selecting individually best options means that we should look closely to how we could facilitate this. But then again, we are in an exploratory phase and we are open to all options.

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