The Participatory Value Evaluation method: an application to the transition towards zero natural gas use at the local level of the neighborhood Hengstdal in Nijmegen

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SUMMARY

The transition towards natural gas-free neighborhoods in the Netherlands is a complex challenge. First of all, ambitious goals were set by the government for 2020 and 2030, but negotiations on how to reach these goals are still ongoing. At the same time, the earthquakes in Groningen and the growing dependency on natural gas from foreign countries are putting pressure on the transition. According to the government, the main responsibility for leading the transition lies with the municipalities. The municipalities, however, indicate that it is still unclear how to find support among the citizens for the transition in their neighborhoods, while Planbureau voor de Leefomgeving (PBL) has shown that those same citizens are allocated a disproportionate share of the costs of this transition.

Traditionally, national or local governments would use a Cost-Benefit Analysis (CBA) to assess the investment decisions that go with environmental policy making on topics like the energy transition. But finding support among citizens for the intended changes in their neighborhood is crucial, especially among the private homeowners: they have the power to decide whether they want to spend money on an alternative for natural gas and what type of alternative they prefer. Both in practice and in academia, it has been argued that classical CBAs adopt a too narrow approach to appropriately assess the societal value of governmental projects.

This thesis will focus on investigating the possibilities of the application of a novel method for the assessment of the transition towards natural gas-free neighborhoods in the Netherlands. The method is called the Participatory Value Evaluation (PVE) method and it is a web-based economic assessment model. The main objective of this thesis is to contribute to the development of the PVE method by researching the applicability of this novel method to the transition towards zero natural gas use at the local level of an existing neighborhood.

The research will address the following knowledge gaps:

- There is no methodological paper available on the design of the PVE method and the content of the related web tool.
- It is the first application of the PVE method on the topic of the transition towards zero natural gas use.
- It is the first application of the PVE method at the local level of a neighborhood.

In order to address these knowledge gaps, the PVE method is applied to a case study on the transition towards zero natural gas use of the neighborhood Hengstdal in Nijmegen. By applying the PVE method on the case study, the main research question in this thesis will be answered: to what extent is it possible to apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood.

There is no methodological paper on the PVE method available. Therefore, existing sources from two prior case studies are used to deduce the steps for the PVE method. Five methodological steps about the design of the PVE method are deduced: choose the context, set the constraint, design the follow-up questions, determine the alternatives and select the attributes. Another four methodological steps are deduced about the composition of the content of the web tool: calculate the effects of the alternatives on the constraint and attribute, compose the content of the introduction and instruction pages, compose the content of the information pages and compose the content of the delegation page. Each step is executed by applying it to the selected case study.

As a result of the research, only 6 respondents filled in the web tool and participated in the experiment. It must be concluded that it was not possible to apply the Participatory Value Evaluation method to the case study about the transition towards zero natural gas use of the neighborhood Hengstdal in Nijmegen. The process of implementing the PVE method is analyzed in order to identify factors that might have complicated the application process in this specific case study. To avoid future applications of the PVE method to suffer from the same complicating factors, several conditions are formulated. If these conditions are met, they could avoid or mitigate the impact of the complicating factors and could therefore make it possible to successfully apply the PVE method. However, future research is necessary in order to determine whether these conditions are sufficient for a successful implementation of the method.

1 INTRODUCTION

When it comes to the consumption of sustainable energy, the Netherlands, with only 5.9% of renewable energy consumed, we are at the bottom of the list in the European Union (EU) in 2016 – only Malta and Luxembourg performed worse (Eurostat, 2018a). According to the sustainability goals set by the EU for 2022, the Netherlands should increase their share of renewable energy in final energy consumption by at least 6.0% (Eurostat, 2018a). However, the Netherlands are not only underperforming compared to other EU Member States: according to Planbureau voor de Leefomgeving (PBL), their own goal set by the Energy agreement in 2013 – 14% share of renewable energy in 2020 – will also not be met (PBL, 2017).

In 2015, new sustainability goals have been added. By signing the Paris Climate Agreement, the Netherlands – and all other participant countries – are no longer allowed to shed carbon emissions after 2050. Additionally, each country has to drastically reduce other greenhouse gases, otherwise it will be impossible to limit global warming to a maximum of 2 degrees (UN, 2015). This calls for a radical reduction of fossil energy use in the Netherlands. Therefore, the energy supply in the Netherlands will have to change significantly in the coming decades (Ministerie van Economische Zaken, 2016).

1.1 Natural gas-free neighborhoods in 2050

To accomplish these goals, set by the earlier energy agreements and the Paris Climate Agreement, one of the major steps planned by the government is to abolish the use of natural gas in the built environment by 2050 (Ministerie van Economische Zaken, 2016). According to the current Minister of Economic Affairs and Climate, this means that – on average – 200,000 houses and other buildings must be made natural gas-free every year until 2050 (Minister Wiebes, 2018).

To illustrate the scope of this transition, a short overview of how dependent Dutch households are on natural gas will be provided. According to the Central Bureau for Statistics (CBS), in 2015, the consumption of natural gas accounted for 71.3 % of the final energy consumption of households (CBS, 2018A). It is important to point out that natural gas is also used in the production of electricity, which accounts for 20.4% of the final energy consumption, and heat, which accounts for 3.0% of the final energy consumption (CBS, 2018B). In 2015, the production of electricity depended for 41.7% on natural gas and the production of heat depended for 44.6% on natural gas (CBS, 2018B). It can be concluded that the average Dutch household still depended for 81.1% on natural gas (CBS, 2018A; CBS, 2018B). Figure 1 shows a complete overview of the final energy consumption of Dutch households in 2015.

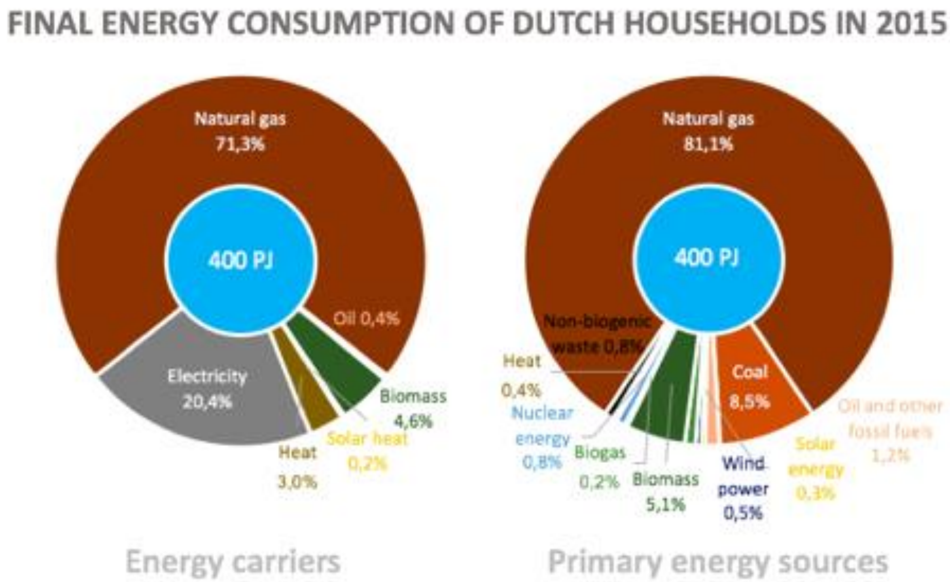

Figure 1. The consumption of Dutch households is equal to 400 PJ in 2015. On the left, the primary energy sources of electricity and heat are not taken into account. On the right, the primary energy sources of electricity and heat are taken into account (CBS, 2018A; CBS, 2018B)

The graph on the left shows the final energy consumption of Dutch households in 2015, distributed by type of energy carrier. The graph on the right shows the final energy consumption of Dutch households in 2015, distributed by type of primary energy source. Here, all the primary energy sources necessary in the production process of the energy carriers displayed on the left are taken into account.

Figure 1 also shows that only 6.5% of the energy consumption of households – of which biomass has the largest share with 5.1% – does not depend on the production of fossil fuels or nuclear energy (CBS, 2018A; CBS, 2018B). The share of biomass is mentioned specifically because there is no consensus on whether it should really be considered a sustainable energy source (PBL, 2014). Without biomass, only 1.4% of the total consumption of households can be called sustainable (CBS, 2018A; CBS, 2018B). It can be concluded that the goal of abolishing the use of natural gas in the built environment by 2050 will be an enormous challenge.

1.2 Earthquakes in Groningen and growing dependency on imports

The earthquakes in Groningen, caused by the extraction of natural gas, have put extra pressure on the need for an energy transition of the built environment. In 2012, the first big earthquake related to the gas extraction occurred in Loppersum (Groningen). Since then, natural gas caused on average 50 earthquakes a year (Rijksoverheid, 2018a). The total natural gas extraction decreased from 84 billion m^3 in 2013 to 52 billion m^3 in 2015 (CBS, 2016a). In March 2018, the government decided that the maximum extraction volume of natural gas from the Groningen field must be below 12 billion m^3 a year until October 2022 and extraction will be stopped completely in the following years (Rijksoverheid, 2018a).

As a result, only gas from the small fields and from abroad will be available in the future for Dutch households. The problem is that virtually all gas fields contain high-calorific gas – except The Groningen gas field – which contains low-calorific gas (Nederlandse Aardolie Maatschappij, 2009). Nitrogen factories can be used to transform high-calorific into low-calorific gas, which have an annual capacity of 20 billion m^3 altogether (N. V. Gasunie, 2014). The government has decided to build a new nitrogen plant in Groningen to increase the capacity, which means that more gas from the small fields and from abroad will be suitable for use by Dutch households starting in 2020 (Rijksoverheid, 2018a). Thus, the earthquakes in Groningen and the growing dependency on natural gas from foreign countries are increasing the pressure on the transition to a natural gas-free built environment by 2050.

1.3 National policies and their impact

Since the instalment of the current government, Rutte III, many policies related to the transition to a natural gas-free built environment by 2050 have been announced. First of all, a new goal was set: to reduce carbon emissions by 49% in 2030 (Regeerakkoord, 2017). Nevertheless, researchers of the PBL have already calculated that the new government policies on energy will only have half of the intended impact on reducing carbon emissions (Koelemeijer et al., 2017a).

Another recent change in policy regards the obligation for DSO's to connect new buildings to the gas network. Because of this obligation, more than 40,000 new houses receive a new gas connection annually. Entirely new gas networks were needed to be built or expanded for 25,000 of these new homes (Rijksoverheid, 2017). However, from July 2018, a change in the gas law ensures that the DSO's are no longer obliged to realize gas connections for users of new houses and other new buildings (RVO, 2018a).

Moreover, a new National Climate and Energy Agreement are currently being negotiated. The idea is that the main points of these agreements will be enacted in the Climate Law (Regeerakkoord, 2017). According to the government, both the Agreement and the Law will give citizens, the business community, municipalities and environmental movements more certainty about the long-term goals of the country (Regeerakkoord, 2017). In February, the Council of Ministers determined the government's commitment to the Climate Agreement. Currently negotiations between the main sectors – built environment, transport, industry, electricity and agriculture – about the content of the Climate Agreement are taking place. The aim is to reach a final agreement in the summer of 2018. These agreements will then be worked out in concrete programs in the second half of the year. It is expected that the implementation of the Climate Agreement will start in 2019 (Rijksoverheid, 2018b).

It can be concluded that with the installment of the Rutte III government and the recent announcements about policy changes, the transition to a natural gas-free built environment by 2050 has started. However, except the very recent announcement of the change in The Gas Law, there are no concrete programs available yet.

1.4 Local solutions provided by local governments

According to the government, the leading role in this transition is reserved for municipalities and the DSO's (Ministerie van Economische Zaken, 2016). The government argues that the transition to a natural gas-free built environment by 2050 must be mainly driven by local administrations, because it requires local solutions: which alternatives for natural gas are suitable as heat sources for heating and hot water is determined by several factors, which are often dependent on local circumstances (RVO, 2017a). This means that an important role is reserved for municipalities and DSO's (Regeerakkoord, 2017).

The first important measure for a successful energy transition is to lower the energy consumption of the built environment by improving insulation (Regeerakkoord, 2017). Then, there are three main types of alternatives for natural gas to be distinguished (RVO, 2018b):

1. District heating networks, a collective system with heat from a renewable source (biofuels or heat from the subsurface) or with residual heat.
2. All electric, both individually and collectively, using heat pumps. The heat pump can extract geothermal heat from air, soil or water near the houses.
3. Other types of gas, in particular biogas.

According to RVO, the switch from natural gas to low-CO_2 alternatives for heating requires a major effort from citizens, businesses, governments and social organizations. The alternatives require substantial (local) investment for the replacement of natural gas-fired installations, in infrastructure and in the production of sustainable energy (RVO, 2017a).

In order to accelerate the transition to natural gas-free neighborhoods, the Government closed a Green Deal with 31 municipalities and 5 DSO’s. All parties that signed the Green Deal are committed to the development of natural gas-free neighborhoods (RVO, 2017a). The main goal of this deal is to enhance knowledge about legislative issues, financing constructions, responsibilities and powers; and planning how to find support among citizens for the intended changes that are required for the transition of the built environment to become natural gas-free (RVO, 2017a).

1.5 Annual costs of the transition

Besides the fact that there is no consensus on leadership and the impact of each composition of alternatives, PBL also pointed out that it is not clear how the costs of removing natural gas from existing neighborhoods will be financed and allocated. This concerns investment in infrastructure, such as district heating networks and electricity network reinforcements, but also investment in the houses for installations and insulation (Koelemeijer et al., 2017a).

PBL made an estimate of the national costs of the transition: constructing the district heating networks is estimated to cost between 500 million and 700 million euros per year until 2030 (Koelemeijer et al., 2017b). Lastly, the national costs of biogas are around 590 million euros per year, while the use of heat pumps will be around 6 billion euros per year (Koelemeijer et al., 2017b). In total, the estimated national expenses of this transition could rise up to 6-7 billion euros a year (Koelemeijer et al., 2017b).

In the same publication, PBL states that construction of district heating networks would be the easiest solution, but political support for this alternative is currently lacking (Koelemeijer et al., 2017b). The coalition agreement aims at transforming only 30,000 to 50,000 homes a year until 2021 into natural gas-free houses. This is in stark contrast with the 200,000 houses that need to be transformed each year in order to abolish natural gas by 2050 (Koelemeijer et al.,2017b). Additionally, according to PBL, in the current policies there is no general support for district heating networks (Koelemeijer et al., 2017b). In some cases, there is financial support only on a local scale (Koelemeijer et al., 2017b).

On the other hand, the national government has many opportunities to support coordination and make the investment in district heating networks more attractive for all parties involved (Koelemeijer et al., 2017b). PBL suggests that the government can reduce investment risks in several ways, for example by making risk capital available via the announced national financing institution Invest-NL, or with subsidized district heating networks – which could make natural gas heating less attractive and more expensive for end users. The latter option could be financed by increasing the energy tax on natural gas and removing the Not-more-than-normal (NMDA) principle or replacing it with a Less-than-normal principle or another system in heat tariff regulation (Koelemeijer et al., 2017b).

The current government is looking into forms of building-related financing, which could be used to make it more attractive for private homeowners to invest in alternatives for natural gas. Financing could take place via pension funds or banks that provide a loan to invest in sustainability. Redemption and interest would be paid from the savings on energy costs. If the loan can be linked to the house, larger investments with a longer maturity become attractive and the risk for both homeowners and financiers remains limited (Regeerakkoord, 2017). However, just as with the other national policies, there are no concrete programs available yet.

1.6 The role of the citizens

Finding support among citizens for the intended changes is crucial according to municipalities (RVO, 2017a). However, according to a recent survey of *Vereniging Eigen Huis* (VEH), an independent interest group of private homeowners with 750,000 members – the majority of these homeowners (82%) expects the government to be the main driver behind the transition (VEH, 2017).

The commitment of these private homeowners to the transition is crucial. 56.2% of the more than 7,640,000 houses in the Netherlands are privately owned (CBS, 2017). This means that owners can decide themselves what alternative for natural gas they prefer. However, the survey of VEH also shows that 40% of the homeowners indicate that they do not have enough information and, therefore, do not understand the matter of energy transition well enough to make an informed choice about which alternative heating source to choose (2017).

It is only not clear, as PBL pointed out, how the costs of the transition of the neighborhoods will be financed and distributed. However, research of CE Delft shows that with the current policies suggested by the government, a disproportionate share of the costs is borne by the citizens, while businesses have a disproportionate share of the benefits (CE Delft, 2017). To illustrate this, Milieu Centraal has calculated that it could cost a private homeowner up to 30,000 euros to make their house completely natural gas-free (Mileu Centraal, 2018-1).

1.7 Cost Benefit Analysis

In order to fulfill the sustainability goals, set by the Netherlands and the rest of the world – and to avoid any more damage in Groningen because of the earthquakes – it is important to make choices about what alternatives are going to replace natural gas and who is responsible for the investments. Traditionally, governments – nationally or locally – would use a Cost-Benefit Analysis (CBA) to assess the investment decisions that go with environmental policy changes like the energy transition (Heffron and McCauley, 2017; Turner, 2007). However, research has shown that the classical CBA is unable to properly reflect the costs and benefits across different affected individuals and groups in society, which are important for the social acceptance of sustainable energy policies (Sovacool et al., 2016; Sovacool and Dworkin, 2015; Turner, 2007). In the case of the transition of neighborhoods towards zero natural gas-use, using a CBA is problematic because there is no consensus on leadership, not enough knowledge on the impact of the alternatives and no clear plan on financing and distributing the costs of removing natural gas from existing neighborhoods, while the support of citizens for local alternatives is crucial (Koelemeijer et al., 2017b).

Additionally, due to the fact that both in practice and in academia it has been argued that classical CBAs adopt a too narrow approach to appropriately assess the societal value of government projects (Ackerman and Heinzerling, 2004; Mouter et al., 2015; Naess, 2006; Barfod & Salling, 2015), it should be explored whether there are more suitable methods to assess the transition towards natural gas-free neighborhoods.

2 RESEARCH PROBLEM

The complex challenge of the transition towards natural gas-free neighborhoods in the Netherlands has already encountered several problems. First of all, ambitious goals were set by the government for 2020 and 2030, but negotiations on how to reach these goals are still ongoing (Ministerie van Economische Zaken, 2016). At the same time, the earthquakes in Groningen and the growing dependency on natural gas from foreign countries are increasing the pressure to achieve a successful transition (CBS, 2016b; Rijksoverheid, 2018a). According to the government, the main responsibility for leading the transition lies with the municipalities (Ministerie van Economische Zaken, 2016). However, it is unclear how the transition is going to be financed, while it requires up to 6-7 billion euros a year (Koelemeijer et al., 2017b). Moreover, the municipalities – who are responsible for leading the transition at the local level – indicate that it is still unclear how to find support among the citizens for the transition in their neighborhoods, while PBL has shown that those same citizens are allocated a disproportionate share of the costs of this transition (RVO, 2017a; CE Delft, 2017).

Traditionally, governments – nationally or locally – would use a Cost-Benefit Analysis (CBA) to assess the investment decisions that go with environmental policy making on topics like the energy transition (Heffron and McCauley, 2017; Turner, 2007). But finding support among citizens for the intended changes in their neighborhood is crucial – especially among the private homeowners. They have the power to decide whether they want to spend money on an alternative for natural gas and what type of alternative they prefer. Both in practice and in academia it has been argued that classical CBAs adopt a too narrow approach to appropriately assess the societal value of government projects (Ackerman and Heinzerling, 2004; Mouter et al., 2015; Naess, 2006; Barfod & Salling, 2015).

2.1 Participatory Value Evaluation method

Given the scope of the problems described in the previous paragraphs, it is not possible to provide a single comprehensive solution for all the problems in one research. Therefore, this thesis will focus on investigating the possibilities of the application of a novel method for the assessment of the transition towards natural gas-free neighborhoods in the Netherlands. The method is called the Participatory Value Evaluation (PVE) method and it is an economic assessment model. The PVE model includes the personal considerations of citizens on different projects by providing explicit information concerning the distribution of benefits, burdens and responsibilities among stakeholders (Mouter et al., 2017).

The Participatory Value Evaluation method is a highly novel method and there is no methodological paper available on the design the PVE method and the content of the related web tool used to gather the citizens' feedback. Moreover, the PVE method has only been applied on two case studies:

1. A regional case study on the assessment of a transport investment plan for the Transport Authority of the municipality of Amsterdam (TAA) (Mouter et al., 2017)[1].
2. A national case study on the assessment of a water management investment plan for the Ministry of Water management and Infrastructure (WM&I) (Mouter et al., 2018).

For both case studies, the TNS NIPO database – which includes 200,000 respondents – was used to select a representative sample of citizens. These citizens were instructed to allocate a fixed budget (the constraint) to the projects that were in line with their preferences; however, the budget constraint made it not possible to choose all the projects. A web tool was developed to provide an overview of several projects and their impact on important values that could drive the preferences of the citizens. A quantitative analysis of the preferred projects showed which values drive citizens to select specific projects (Mouter et al., 2017; Mouter et al., 2018).

In this thesis, the PVE method will be applied to the transition towards zero natural gas use at the local level of an existing neighborhood. To research the applicability of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood, a practice-oriented research is suggested: the PVE method will be applied to a case study on the transition towards zero natural gas use at the local level of an existing neighborhood for a municipality. The residents of the neighborhood will be instructed to choose an alternative to natural gas which is in line with their preferences. However, their choices should also meet the sustainability constraint set by the municipality of the neighborhood. A web tool will be developed to provide an overview of each alternative and their impact on important values that could drive the preferences of the citizens.

The case study that is analyzed in this research differs on two levels from the previous case studies: both in terms of the topic analyzed and the scale of the research conducted. The topic of the case study in this thesis regards the transition of a neighborhood towards zero natural gas use, while the previous two case studies dealt with transport projects and water management investments, respectively. Moreover, the case study in this research has a different scale than the previous ones: it regards the local level of a single neighborhood, while the previous applications of the PVE method were at the regional level – for TAA Amsterdam – and at the national level – for the Ministry of Water

[1] The demo version is available on the following website: http://www.participatie-begroting.nl

Management and Infrastructure. The research on the two previous case studies and the research conducted in the case study in thesis are compared in Figure 2.

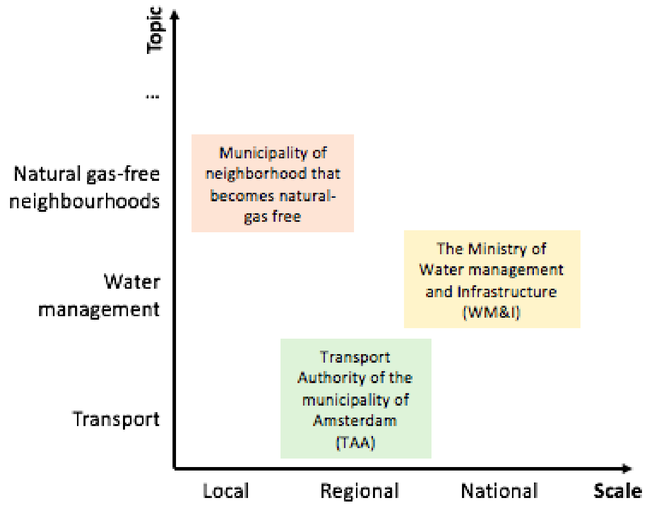

Figure 2. Comparison between the two previous case study and the case study conducted in this thesis.

2.2 Knowledge gaps and problem statement

In order to assess the applicability of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood, three knowledge gaps must be addressed:

- There is no methodological paper available on the design of the PVE method and the content of the related web tool.
- It is the first application of the PVE method on the topic of the transition towards zero natural gas use.
- It is the first application of the PVE method at the local level of a neighborhood.

Based on the knowledge gaps, the following problem statement is formulated:

It is the first application of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood and there is no methodological paper available on the design of the PVE method and the content of the web tool, while the applicability of the PVE method in this context can only be assessed by implementing the method on a real-world case.

This problem will be addressed by the research conducted in this thesis.

2.3 Research objectives and expected deliverables

In order to address the problem and the knowledge gaps introduced in Paragraph 2.2, the objective of this thesis will be:

To contribute to the development of the PVE method by researching the applicability of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood.

To achieve this objective, the following three main steps are followed which will lead to three according deliverables, shown in Table 1:

STEP	DELIVERABLE
1. Deducing the methodological steps for the PVE method based on the available prior research and altering the methodological steps for the PVE accordingly.	1. A set of methodological steps for the PVE method.
2. Conduct the required research for the design of the PVE method and the content of the web tool.	2. A specific web tool for the case study.
3. Analyzing the implementation process of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood.	3. Evaluation of the applicability of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood

Table 1. Three main steps are followed that will lead to three according deliverables

2.4 Scientific relevance

This thesis will contribute to the scientific knowledge on the application of the PVE method by implementing this new method in a real-life case study. The scientific relevance of this research is threefold. First, deducing the methodological steps that are necessary for the implementation of the PVE method – discussed in Chapter 5 – will contribute to the academic discussion on the development of the PVE method. In particular, the methodological steps could partially fill the lack of a methodological research paper on the theoretical aspects of the PVE method. The methodological steps can then be applied in future research on the application of the PVE method. Thus, the first part of this research will address the knowledge gap 1 identified in paragraph 2.3.

Second, this research will test the applicability of the PVE method on a new topic and at a new level. This is a new practical application of the method that has not been explored before. The research conducted in this thesis will provide a thorough assessment of the complicating factors that occurred during the implementation of the model on this specific topic. Future research is necessary to identify whether the complicating factors are caused by either the new topic, the new level of analysis or the PVE method in general.

Then, in order to avoid future applications of the PVE method to suffer from the same complicating factors, a list of conditions for a successful implementation of the method will be formulated. However, future research is required in order to determine whether these conditions – if met – will be sufficient. This analysis of the complicating factors aims at addressing the knowledge gaps 2 and 3 identified in paragraph 2.3.

2.5 Societal relevance

On top of its scientific relevance, the research conducted here also has a potential significant impact on society. As mentioned in the introduction, private homeowners play a key role in the transition of neighborhoods towards zero natural gas use. Their support to the transition is crucial, but in order to gain their support it is necessary to understand their preferences in terms of the possible alternatives to natural gas. However, there is no clarity yet on what their preferences are. Applying the PVE method to the transition of neighborhoods towards a natural gas-free built environment has the potential to offer policymakers an important tool to investigate the citizens' preferences on the possible alternatives to natural gas, and to include these preferences in their policy decisions. If energy transition policies are developed using the citizens' preferences as an input, they are more likely to gain the support of those same citizens.

Finally, the PVE method can be an important communication tool. As mentioned, 40% of the homeowners indicate that they do not have enough information and do not understand the matter of energy transition well enough to make an informed choice about which alternative heating source to choose (VEH, 2017). The web tool developed for this thesis can be used as a novel way to provide information about the possible alternatives to natural gas to the homeowners – at least in the specific neighborhood selected as case study. They can use this information as a basis for their preferences, and hence the PVE method can contribute to raising the understanding of the topic among one of the key players of the transition.

3 RESEARCH QUESTIONS

To reach the objective of this thesis, the following main research question should be answered:

To what extent is it possible to apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood?

In order to answer the main research question, seven sub questions are formulated. An overview and explanation of the sub questions is provided in Table 2:

	QUESTION	EXPLANATION
SQ1.	**What methodological steps are needed to apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood?**	The PVE method is a novel method that has only been applied twice. There is no methodological paper on the PVE method available. The existing prior research on two case studies, for the Transport Authority of the municipality of Amsterdam and the Ministry of Water Management and Infrastructure, will be used to deduce the steps for the PVE method. The methodological steps must be modified in order to apply the method to the transition at the local level towards a natural gas-free neighborhood. This will be addressed in Chapter 5.
SQ2.	**What is the context of the case study in which the Participatory**	This research is the first application of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood. Following the example set by previous applications of the PVE method, a practice-oriented research is suggested through the analysis of one in-depth case study. The first

	Value Evaluation method is applied?	step is to select a suitable case study. Then, a clear overview must be provided of the current context in which the transition of the selected neighborhood to zero natural gas use takes place. Therefore, first the main stakeholders in the case study must be identified. Moreover, the key characteristics of the case study in terms of the socio-demographic variables of the neighborhood should be analyzed. Lastly, the most important features of the current energy system of the case study neighborhood are investigated. These points together will provide a broad overview of the context in which the PVE method is applied. The analysis of the context is used to conduct step 1, 2 and 3 of the PVE method. All these steps will be addressed in Chapter 6.
SQ3.	**What are the available alternatives to natural gas for the transition of the case study neighborhood?**	The next step is to provide a structured overview of the available alternatives for natural gas which could be implemented in Hengstdal, which is step 4 of the PVE method. This is important, because in order to be able to calculate the effects of each alternative on the attributes with the Energy Transition Model, the alternatives must be first determined. This will be addressed in Chapter 7.
SQ4.	**What are the attributes regarding the transition towards zero natural gas use?**	The key objective of this chapter is to present an overview of the attributes of the PVE method, which is step 5 of the PVE method. The attributes must reflect the most important values regarding the transition of Hengstdal according to its residents. Therefore, the most important values must be identified first. This will be addressed in Chapter 8.
SQ5.	**What are the effects of each alternative on the attributes regarding the transition towards zero natural gas use at the local**	The key goal of this chapter is to provide an overview of the effects of each alternative on the constraint and attributes, which is step 6 of the PVE method. This is important because, in order to provide a clear overview of all the effects of each alternative included in the web tool, first all the effects must be calculated, which requires a total of 144 calculations. In order to conduct these calculations, the Energy Transition Model will be

	level of the case study neighborhood?	used. The model provides the opportunity to design energy scenarios in order to calculate the effects of each alternative. This will be addressed in Chapter 9.
SQ6.	**How is the content of the web tool composed for the case study?**	In order to gather information about the preferences of the residents of the case study neighborhood, a clear and understandable web tool is needed that provides a clear overview of the effects of each alternative to the residents and meets the expectations and constraints set by the selected municipality. This will be addressed in Chapter 10.
SQ7.	**What factors complicate the application of the PVE method at the local level to the transition of a neighborhood to zero natural gas use?**	The process of the application of the PVE method must be analyzed in order to identify complicating factors and to provide a list of conditions that must be met for a successful application. This analysis will determine the applicability of the PVE method in assisting the decision-making process on the transition of a neighborhood towards zero natural gas use, answering the main research question. This will be addressed in Chapter 11.

Table 2. An overview and explanation of the seven sub questions which need to be answered first in order to answer the main research question.

4 RESEARCH APPROACH

The research in this thesis will address a practical problem: the applicability of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood. To analyze the applicability, a practice-oriented research is suggested. According to the study of Verschuren & Doorewaard (2010), a case study is the appropriate research strategy.

However, the research strategy as a whole can be seen as an embedded research strategy: a single in-depth case study about the application of the Participatory Value Evaluation method, which is shown schematically in Figure 3. The PVE method is applied to the case study, but in order to do that it is first necessary to determine the steps of the PVE method. Then, after the application of the PVE method to the case study, the process of the application will be evaluated. The according sub questions, which can be found in Chapter 3, are color-coded to indicate whether they refer to the PVE method (blue) or to the case study (green), as shown in Figure 3.

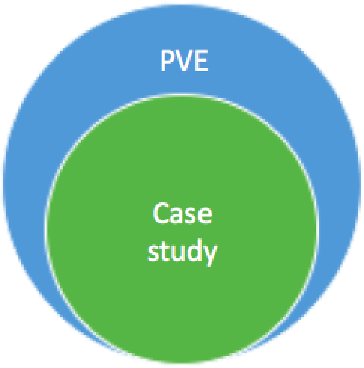

Figure 3. Schematic overview of research strategy

Mouter et al. (2017a) define each application of the PVE method in the transportation investment plan as an experiment. These experiments have survey elements in them, since each participant is asked to fill in follow-up questions. Thus, the application of the PVE method in this thesis follows the main research strategy of a case study, but it has also experimental and survey aspects in it.

The main disadvantage of experiments and case studies is external validity. For the PVE method to gain external validity, it should be applied on a wide variety of case studies. This thesis will contribute to this goal by applying the PVE method on a new topic and a new level. Thus, this is an inductive research where the goal is to explore the applicability of the PVE method and analyze the problems that could be encountered. This analysis can result in a set of conditions – which should be further researched in future case studies – that should be met for a successful implementation of the PVE method.

One strategy to deal with the problem of external validity is to choose a strategic sample. With a strategic sample, the selection of the case study is consciously guided by the information the research intends to extract from the case study (Verschuren & Doorewaard, 2010). Therefore, based on the main research question, the case study should have the following requirements:

1. The selected neighborhood must have committed to the goal of transitioning towards zero natural gas use.
2. The selected neighborhood must not be newly built, because the focus lies on the transition of existing neighborhoods.
3. The selected municipality – of the case study neighborhood – must be willing to cooperate, to provide information about the neighborhood and to participate in the experiment.
4. The timeline of the stakeholders must match with the timeline of conducting the research. The stakeholders must be willing to implement the PVE method in the short-term.

These four requirements will be used to choose an appropriate case study for this research.

Another way to mitigate the impact of the singular case study is to consult at least three different type of sources, which is called source triangulation. Each source has its own advantages and disadvantages and, overall, they provide a more balanced picture of reality (Verschuren & Doorewaard, 2010). For each sub-question, when appropriate, articles (literature research), documents (recorded media, but addressed to a specific public), media (addressed to a wider and undefined public) and experts are consulted. For each question, the research method and sources are displayed in Table 3.

	RESEARCH QUESTION	RESEARCH APPROACH	SOURCES
SQ1.	What methodological steps are needed to apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood?	Triangulation of sources: Desk research Interviews with expert Interactive learning from peer project	Previous case studies PVE method experts Web tool
SQ2.	What is the context of the case study in which the Participatory Value Evaluation method is applied?	PVE method: Desk research Interviews with expert	CBS data Reports on neighborhood Stakeholders
SQ3.	What are the available alternatives to natural gas for the transition of the case study neighborhood?	PVE method: Desk research Interviews with experts	Reports neighborhood Government reports Surveys
SQ4.	What are the attributes regarding the transition towards zero natural gas use?	PVE method: Desk research	Government reports Surveys

SQ5.	What are the effects of each alternative on the attributes regarding the transition towards zero natural gas use at the local level of the case study neighborhood?	PVE method: Desk research Interviews with experts Quantitative analysis with linear model: ETM	CBS data Reports on neighborhood Energy Transition Model Previous rapports of ETM
SQ6.	How is the content of the web tool composed for the case study?	PVE method: Desk research Interviews with experts Comparison case study	Web tool TAA Stakeholders Web developer Experts on PVE method
SQ7.	What factors complicate the application of the PVE method at the local level to the transition of a neighborhood to zero natural gas use?	Process analysis Comparison case study	Data gathered by web tool Stakeholders Description of application process PVE

Table 3 An overview is given of the research approach and the methodology

In order to conduct the research for this thesis, collaboration with several parties was necessary. A different party was involved in the production of each deliverable, as shown in Table 4. The following parties were considered for this collaboration:

COLLABORATION TOPIC	COLLABORATION PARTNERS	CHAPTERS
1. Deduction and alteration of the methodological steps of the PVE	- Paul Koster - Ministry of WM&I - Municipality of Nijmegen - Duurzaam Hengstdal	Chapter 5 and 6
3. New application of the ETM	- Quintel Intelligence	Chapter 9
4. Design of the web tool for case study	- Web developer	Chapter 10

Table 4. The deliverables of this thesis are shown on the left of this table. On the right, it is shown what collaborations are required in order to produce these deliverables.

5 DEDUCTION OF METHODOLOGICAL STEPS ON THE DESIGN AND IMPLEMENTATION OF THE PVE METHOD

The main goal of this chapter is to provide an overview of the methodological steps needed to design the PVE method for the transition towards zero natural gas use at the local level of an existing neighborhood and to explain how to compose the content of the web tool. This is important, because there is currently no methodological paper available yet that prescribes clearly how to design the PVE method in general and how to connect the content of the web tool to the design of the PVE method.

Therefore, both the design of the PVE method and the composition of the content of the web tool must be deduced from prior research. The PVE has been applied only in two prior case studies. A case study for the Transport Authority of the municipality of Amsterdam to receive citizens' feedback on various transport projects, and another case study for the Ministry of Water Management and Infrastructure (WM&I) about the assessment of the long-term ambitions on river management.

The small number of prior studies makes it difficult to validate the proposed deduction. An alternative approach is therefore suggested for the validation: an iterative process, where the creators of the method – Niek Mouter and Paul Koster – are consulted during the design of the method in order to check whether the proposed methodological steps are reflecting the underlying concepts on which the method was originally created.

First, the sources regarding the two case studies are introduced in Paragraph 5.1. Then, an analysis of these sources is given in Paragraph 5.2, which leads to the deduction of five methodological steps for the *design* of the PVE method and four methodological steps for the *implementation* of the PVE method. Lastly, Paragraph 5.3 will discuss possible alterations to the methodological steps to adapt to the specific case study. As explained in Chapter 2, the implementation of the PVE method on the topic of the transition of a neighborhood to zero natural gas use at the local level differs in two ways from the previous case studies: the scale (local instead of regional or national) and the topic (the transition of a neighborhood towards zero natural gas use, rather than transport projects or water management). Therefore, alterations in the PVE methodology might be necessary to address both differences. The chapter ends with an overview in Paragraph 5.4 of the specific methodological steps of the PVE method conducted in this thesis.

5.1 Overview of prior research

As explained before, there is no methodological paper on the design of PVE experiments available yet. One case study on the implementation of the PVE method have already been carried out before the start of this thesis, while another case study was still ongoing while the research in this thesis was being conducted. From these two case studies, three useful sources were identified:

1. From the Transport Authority of the municipality of Amsterdam (TAA) case study:
    a. **Conference paper:** The PVE method is developed by Mouter et al. in the context of assessing a transport investment plan for the TAA. A conference paper was written on the application of this method in evaluating transport policy decisions for the TAA (Mouter et al., 2017).
    b. **Web tool:** Due to the fact that the PVE method is a web-based economic assessment model, an according web tool was developed for this case study. The main purpose of the web tool is to provide an overview of the effects of each project on the constraint and attributes. This web tool is still available as a demo version.[2]
2. From the Ministry of Water Management and Infrastructure (WM&I) case study:
    a. **Observations:** During the course of this case study, the PVE method was applied on assessing a river management investment plan for the Ministry of WM&I. Several meetings were attended with Niek Mouter and two representatives of the Ministry of Water Management and Infrastructure. These meetings provided the opportunity to observe the process that precedes the implementation of the PVE method.

5.2 The deduction of the methodological steps of the PVE method

Now that the available resources are identified, a summary of each source will be provided. Each source provides input for the deduction of the set of nine methodological steps:

1. The conference paper led to five steps on the **design** of the PVE method
2. The web tool for the TAA lead to four steps on how to compose the content of the web tool, which is used to **implement** the PVE method.
3. The observations of the meetings led to **additional conditions** for the design of the PVE method, content of the web tool and the implementation of the PVE method.

[2] The demo version is available on the following website: http://www.participatie-begroting.nl

5.2.1 Conference paper

The first source is a conference paper titled: "*Power to the People: Applying participatory budgeting to evaluate transport policy decisions*". The title of the paper does not mention the PVE method, which - by then - was still called the Participatory Budgeting Method. The paper deals with the application of the method in evaluating transport policy decisions for the TAA (Mouter et al., 2017). Both the methodology and the expected results sections of this paper are used as a starting point to deduce the methodological steps.

This paper shows that the essence of the method is as follows. In a certain **context (step 1)**, the Transport Authority of the municipality of Amsterdam needs to improve the transport system in the period 2030-2032, under the specific **constraint (step 2)** of 100 million euros budget. The respondents must choose a set of **projects (step 3)** among a pool of 16 possible transport-related projects. These projects are categorized by several **attributes (step 4)**: costs, time savings for citizens that benefit from the project, safety improvements, changes in noise pollution and changes in air pollution. Of the 16 projects, some are large projects (30-40 million each), and some are smaller projects (15 million each). The budget constraint makes it impossible to choose all the projects. Therefore, respondents are forced to evaluate each project based on the attributes. This can provide insight about what values drive the respondents' choices.

After the respondents indicated their preferences, they are requested to answer three types of **follow-up qualitative questions (step 5)**. First, the respondents are asked to motivate their choices; second, then they have to provide relevant background information; and third, they have to indicate to which extent they feel that participating in the experiment contributes to their sense of citizenship.

The results on the preferred set of alternatives provide the input for the qualitative analysis. The results show which attributes drive the respondents' selection of the projects. The answers given to the follow-up questions, instead, provide a three-fold result. First, they allow to gain more insight on why citizens assign more value to one attribute than to another. Second, they provide an indication about whether the PVE method contributes to the feeling of citizenship of the respondents. Last, they show what types of citizens participate in the experiment and their background information could then be used to identify the main characteristics of groups with similar preferences.

The conference paper allows to deduce five methodological **<u>steps for the design of the PVE method</u>**, which are shown in Figure 4. ***Step 1*** is to choose the context. Then, the constraint is set in ***step 2***. In ***steps 3 and 4***, the possible projects and their attributes are selected. Lastly, a set of follow-up qualitative questions should be designed in ***step 5.*** These steps together represent the preparation phase that precedes the design of the web tool.

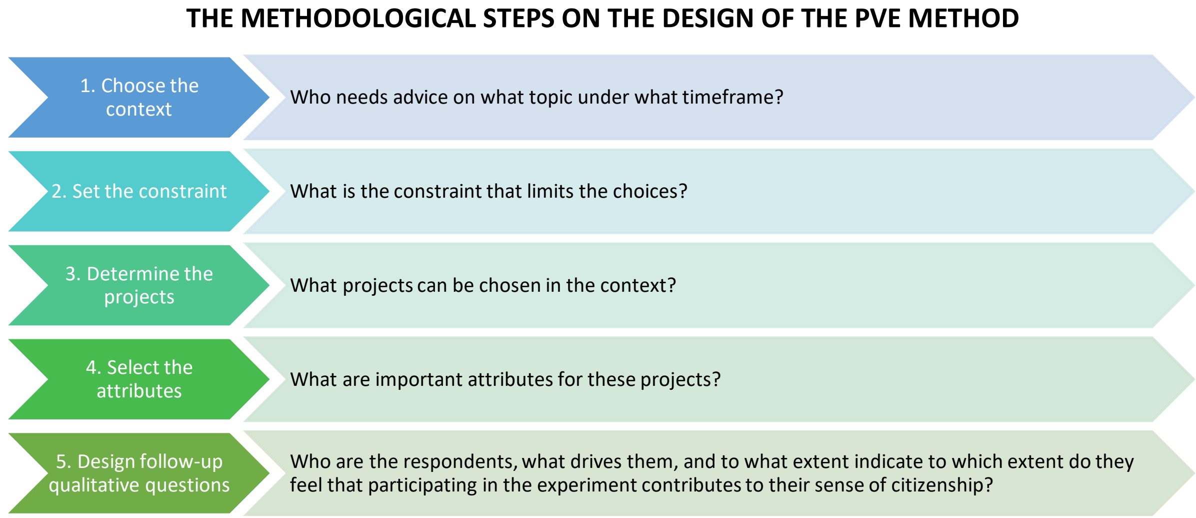

Figure 4. The first five steps of the PVE method, that form together the design of the PVE method, deduced from the conference paper.

5.2.2 Web tool

The web tool is used for the implementation of the PVE method. It provides a clear overview of the effects of each project on the constraint and attributes to the respondents, offer them a basis for choosing their preferred projects. Moreover, the web tool allows the researcher to gather quantitative and qualitative data in order to analyze the values that drive the respondents' choices.

However, in order to implement the web tool, it is first necessary to decide upon the content of the web tool. The web tool developed for the TAA case study was analyzed for this purpose. This analysis allows to define the additional methodological steps that are necessary for determining the content of the web tool used in this research. Consequently, the content of the following web pages of the TAA web tool is analyzed:

1. Introduction and instruction pages
2. Main page
3. Information pages
4. Delegation page

First, it should be noted that the comparison page and selection page are omitted because these pages do not contain any additional information, they are rather a composition of the content of the other pages. Second, the content of the introduction and instruction pages is analyzed together because no clear division exists between the content of those pages. Last, an analysis of the follow-up questions has already been provided in the previous paragraph (step 5 of the design of the PVE method) and therefore is omitted. An overview of the deduction is given in Appendix A.

From this analysis, the following four steps on the composition of the content of the web tool were deduced, as shown in Figure 5.

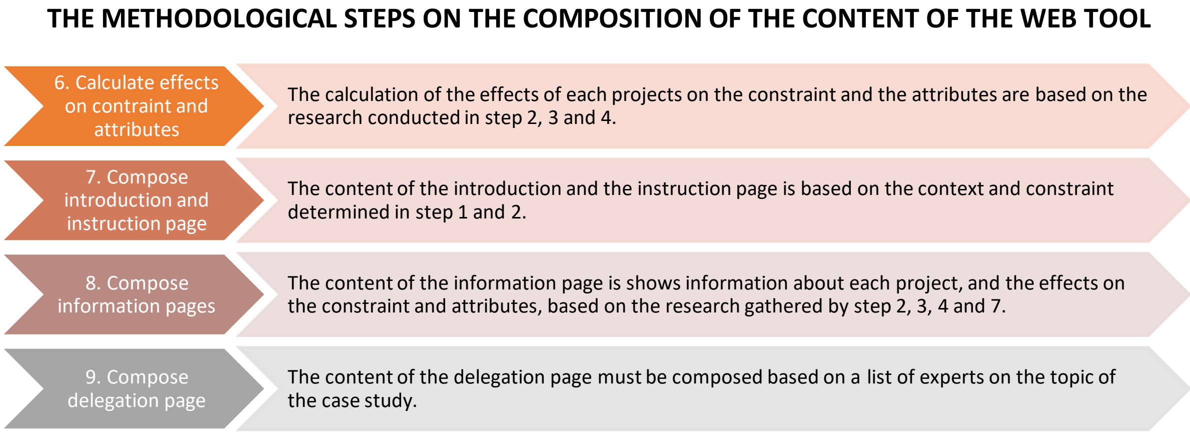

Figure 5. The second four steps of the PVE method for the content of the web tool, deduced from the web tool.

In order to provide to the citizens a clear overview of the effects of each project on the constraint and attributes, these effects first need to be calculated in **step 6.** The research conducted on the constraint (chosen in step 2), the projects (determined in step 3), and the attributes (selected in step 4) is used as input for the calculations. Then, the content of the introduction and instruction pages is determined in **step 7**, using as a basis the context and constraint (decided upon in step 1 and step 2). Step 7 explains what is expected of the respondents under what circumstances. Next, based on the effects calculated in step 6 and the research conducted on the constraint (step 2), the projects (step 3), and the attributes (step 4), the content of the information page on each project can be composed, which is **step 8**. The last step is to decide upon the content of the delegation page. On this page, the respondents can choose to delegate their decision to an expert. Therefore, a list of experts must be prepared in **step 9**.

5.2.3 Observations from meetings with Ministry of WM&I

The last source that is used are the observations made during the several meetings with Niek Mouter, the creator of the method, and two representatives of the Ministry of Water Management and Infrastructure about a new application of the PVE method: assessing the long-term ambitions on river management for the Ministry of Water Management and Infrastructure. During these meetings, remarks were made on the design of the PVE method, the composition of the content of the web tool and the implementation of the PVE method. The remarks were used to determine conditions which should be taken into account when conducting the methodological steps of the PVE method. The most important ones are listed here:

Conditions for the design of the PVE method:

- The context of the PVE method must be an accurate representation of the ‘real word’ by choosing a realistic constraint and set of projects
- Not more than 16 projects should be chosen, of which one should be a benchmark project that respondents are familiar with.
- There should be around 8 attributes to characterize the projects.

Conditions for the composition of the content of the web tool:

- The content of web tool must be realistic in order to encourage people to take the experiment seriously.
- The web tool must provide the residents of Hengstdal with a complete overview of the alternatives so that they can decide independently whether an alternative is desirable or not.
- The boundaries to participate in the experiment must be relatively low:
    - The language used in the web tool should be very clear – it should be understandable for everybody.
    - Completing the web tool should not take more than 30 minutes.
    - The web tool should be accessible online – people should have the choice about when and where they complete the questions on the web tool.

Conditions for the implementation of the PVE method:

- The number of respondents should be around 500, which is equal to the number of respondents that participated in each experiment conducted for the previous case studies. For those studies, the TNS NIPO database was used to select a representative sample. However, a significant research budget is required to use the database. Given the unavailability of any funding, it was not possible to use the TNS NIPO database for this research.

Now that the methodological steps of the PVE method are deducted, the next step to be discussed is whether alterations of the methodological steps are required in order to address the fact that this case study is on a local level, instead of regional or national, and on a new topic, the transition of a neighborhood towards becoming natural gas-free.

5.3 Alterations on the methodological steps of the PVE method

Now that a set of 9 methodological steps of the PVE has been deduced from the three sources presented above, it is time to discuss the necessary alterations. This paragraph will only discuss those steps that require alternations and present the relative changes.

5.3.1 Set the constraint (Step 2)

The constraint in this case study differs from the previous case studies. In the previous case studies, the constraint was the budget. However, in this case study, the constraint must be based on the sustainability objective set by municipality where the case study neighborhood is located. The research on setting the constraint will be presented in Chapter 6.

5.3.2 Determine alternatives (Step 3 → Step 4)

In the former case studies, respondents could choose between 16 projects. In this case study, the projects should consist of various alternatives for the use of natural gas. Therefore, they will be referred to as “alternatives” in the rest of the thesis. Additionally, the local energy system of the case study neighborhood must be studied in order to identify viable alternatives for the use of natural gas that can be applied locally. Therefore, first the local energy system of the case study neighborhood is studied in Chapter 6. Then, the research on determining what alternatives should be used in the PVE method is presented in Chapter 7.

5.3.3 Design follow-up qualitative questions (Step 5 → Step 3)

There are three types of follow-up questions asked to the respondents in the TAA case study web tool: (1) to further explain their motivation for their preferred projects, (2) to indicate to what extent the respondents feel that participating in the experiment contributes to their feeling of citizenship and (3) some questions about the background of the respondent. The first two types of questions can be applied to this case study as well, because they are not dependent on the specific case study.

The background questions, instead, were specially designed to address the TAA case study, i.e. whether the respondent possesses a car, a driving license or a public transport card. For the purpose of the research carried out in this thesis, new questions should be designed to gather useful information about the background of the respondents regarding the transition towards zero natural gas use.

To be able to design these questions, research should be conducted to identify relevant background variables that could be of influence on the preferences of the citizens about each alternative and that can be used to interpret the results. The number of questions will be limited to not more than five in order to avoid an excessive burden for the respondents, which could prevent them from participating in the experiment.

The research necessary for the design of the questions is presented in Chapter 6, which means that the design of the follow-up questions will discussed before the determination of the alternatives and selection of the attributes. Therefore, the order of the steps in this thesis will change: the design of the follow-up questions will be step 3, the determination of the alternatives will be step 4 and selection of the attributes will be step 5.

5.3.4 Calculate the scores (step 6)

The PVE method does not include a specific system to assess the different alternatives. This part of the research was carried out by exploring a new application of an existing model, the Energy Transition Model (ETM). The ETM is developed by Quintel Intelligence and is an independent, comprehensive and fact-based energy model that is used by governments, corporations, NGOs and educators to evaluate energy scenarios for many different projects. In the context of this thesis, the ETM is used to calculate the impact of the possible alternatives (identified in step 3) on the constraint (identified in step 2) and the relevant attributes (identified in step 4). Research needs to be conducted in order to explore the workings of the ETM, which will be presented in Chapter 9.

5.3.5 Select the experts (Step 9)

In both case studies, several experts were consulted to provide their advice on what projects to choose. However, due to time constraints, a less time-consuming option for the expert page is suggested for this research. Respondents will be able to delegate their decision without being able to choose a specific expert and without knowing what the results of the delegation will be. This option will provide a clear indication on how many respondents do not want to have the responsibility of deciding over the transition towards zero natural gas use. This will be discussed in Chapter 10.

5.4 The methodological steps of the PVE method for the transition towards zero natural gas use at the local level of an existing neighborhood

Now that all the alterations of the methodological steps are discussed, a brief overview of the methodological steps for the PVE method adjusted to the case study of this research is given in Figure 6. The figure also indicates in which chapter each step will discussed in detail.

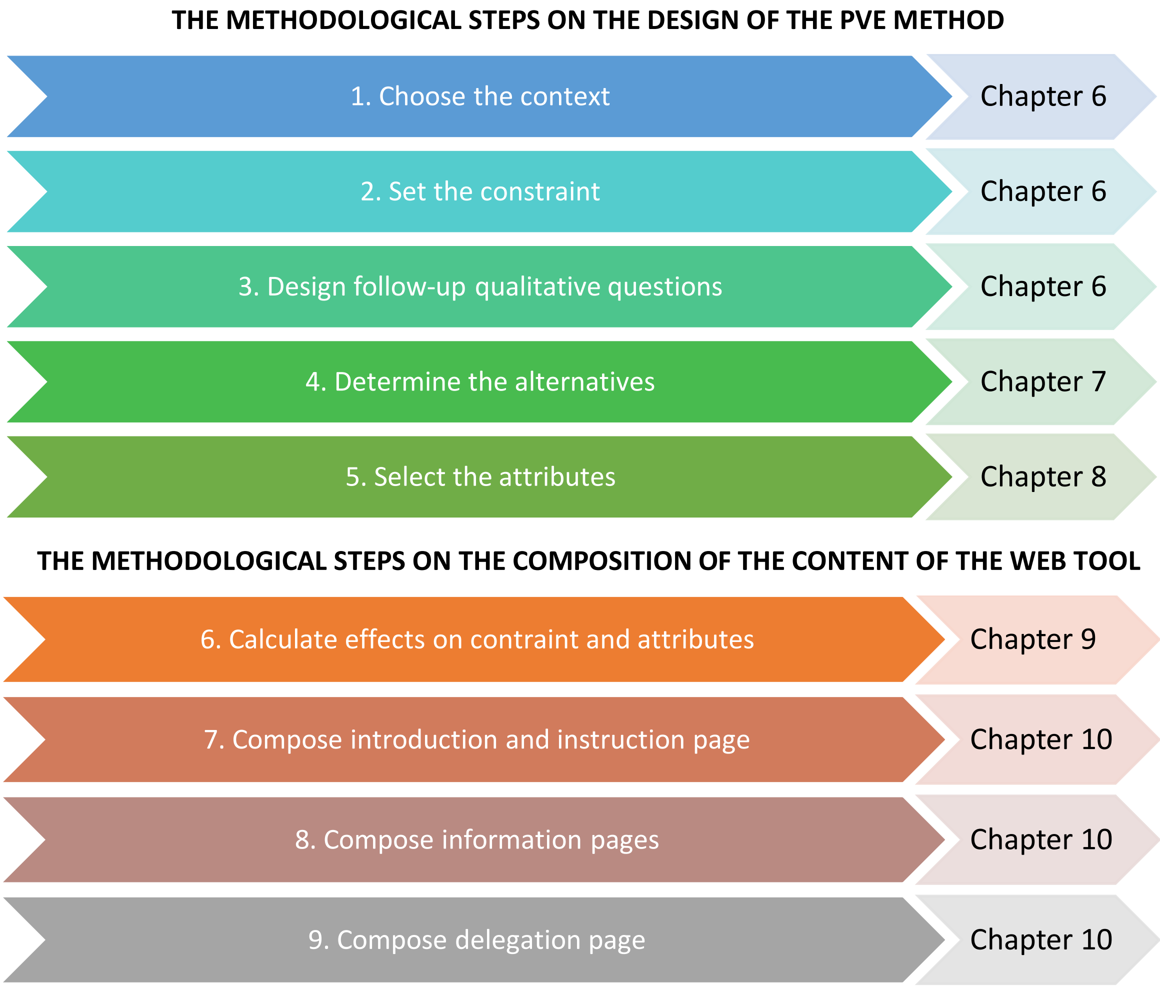

Figure 6. Overview of methodological steps on how to design the PVE method for the transition towards zero natural gas use at the local level of an existing neighborhood and how to compose the content of the web tool accordingly in order to implement the PVE method.

Now that the methodological steps of the PVE method are completed, the next step is to introduce the case study and to execute the methodological steps of the PVE method which were deduced in this chapter.

6 CURRENT CONTEXT OF CASE STUDY NEIGHBORHOOD

The key objective of this chapter is to provide a clear overview of the current context in which the transition of the selected neighborhood to zero natural gas use takes place. Therefore, it is first necessary to select a suitable case study. The selection of the case study – the neighborhood Hengstdal in Nijmegen – is explained in Paragraph 6.1. Then, an overview of the main stakeholders of the case study is given in Paragraph 6.2. The information gathered in these paragraphs is used to execute step 1 and 2 of the PVE method. Thereafter, Paragraph 6.3 provides an overview of the key differences and similarities between Hengstdal and the Netherlands as a whole, which makes it possible to interpret the results of the case study in a broader context. Lastly, the chapter concludes with providing an overview of the key aspects of Hengstdal's energy system in Paragraph 6.4. The information gathered in the last paragraph is used to execute step 3 of the PVE method. Additionally, the data gathered on the socio-demographic variables and the energy system in this chapter will be used as input for the start-scenario of the ETM model, which will be discussed in Chapter 9.

6.1 The selection of the case study

The case study that is selected must fulfill the requirements that are introduced in Chapter 4, which are:

1. The selected neighborhood must have committed to the goal of transitioning towards zero natural gas use.
2. The selected neighborhood must not be newly built, because the focus lies on the transition of existing neighborhoods.
3. The selected municipality – of the case study neighborhood – must be willing to cooperate, to provide information about the neighborhood and to participate in the experiment.
4. The timeline of the stakeholders must match with the timeline of conducting the research. The stakeholders must be willing to implement the PVE method in the short-term.

To find a case study that fulfills these requirements, the starting point was to look at the participants of the *Green Deal: Natural Gas-free Neighborhoods*, discussed in the introduction. The municipality of Nijmegen, Green Capital of Europe in 2018, was one of the municipalities that signed the deal. Nijmegen aims at having 75% of the built environment energy-neutral by 2030. In 2045, the city wants to be completely energy-neutral, as already stated in the municipality's Sustainability Agenda of 2011. According to CE Delft (2017), a municipality is energy-neutral when its energy demand is fully covered by renewable resources. Since natural gas is not a renewable resource, being energy-neutral implies using no natural gas as an energy source. These objectives put the municipality of Nijmegen in an active and ambitious position for the realization of a sustainable heat supply.

As part of the Green Deal, the municipality of Nijmegen has designated the Hengstdal district to be the pilot case (HIER Verwarmt, 2017) and the transformation of Hengstdal towards a natural gas-free neighborhood will be the first step to achieve the objectives of the deal (HIER Verwarmt, 2017). One of the main reasons for Nijmegen to choose Hengstdal as a pilot is the fact that parts of the gas network in this district must be replaced in the coming years, which offers a good opportunity to investigate whether the required investment for the gas network could instead be invested in a sustainable alternative (HIER Verwarmt, 2017).

Meetings were conducted to make sure that the municipality and the most relevant stakeholders – an analysis of the key stakeholders will be provided in the next paragraph – were willing to cooperate with this research in a suitable timeframe. One of the main stakeholders is the residents' initiative, *Duurzaam Hengstdal,* which has the main focus of making the neighborhood more sustainable. From these talks, it appeared that both the municipality of Nijmegen and the Duurzaam Hengstdal initiative were enthusiastic and willing to cooperate within the timeframe of this thesis.

Thus, it can be concluded that all requirements were met. Therefore, the neighborhood Hengstdal in Nijmegen was chosen as the case study for this thesis.

1. Choose the context

The information gathered in this paragraph is used to execute step 1 and 2 of the PVE method. The context of the PVE method in this case study is as follows: the municipality of Nijmegen aims to become energy neutral in 2045. The first step of this transition is to transform the neighborhood Hengstdal towards zero natural gas use in 2045. There are several alternatives for natural gas and it wants to consult the residents of Hengstdal to investigate which alternative is preferred.

2. Set the constraint

The constraint is based on the sustainability objectives of the municipality. Nijmegen has the ambition to make Hengstdal natural gas-free, which is part of a greater ambition to make the built environment to completely energy-neutral in 2045. Ideally, the constraint of the PVE method should take into account both ambitions. According to CE Delft (2017), a municipality is energy-neutral when its energy demand is fully covered by renewable resources. Since natural gas is not a renewable resource, being energy-neutral implies using no natural gas as an energy source. Therefore, the constraint in this case study is for Hengstdal to become energy-neutral by 2045, which is measured as the share of renewable energy sources used by households in Hengstdal in 2045. In the next paragraph, an analysis of the key stakeholders of the case study of Hengstdal is provided.

6.2 The key stakeholders in Hengstdal

In order to determine who are the key stakeholders in the case study of Hengstdal regarding the application of the PVE method, a power versus interest grids is used. The grid is used to identify which stakeholders' interest and power bases must be taken into account (Eden and Ackermann, 1998) in order to be able to apply the PVE method in Hengstdal. Four categories of stakeholders can be identified: players who have both an interest and significant power; subjects who have an interest but little power; context setters who have power but little direct interest; the crowd which consists of stakeholders with little interest or power (Eden & Ackermann, 1998).

Figure 7 shows an overview of the identifications of the main stakeholders in the Hengstdal case study.

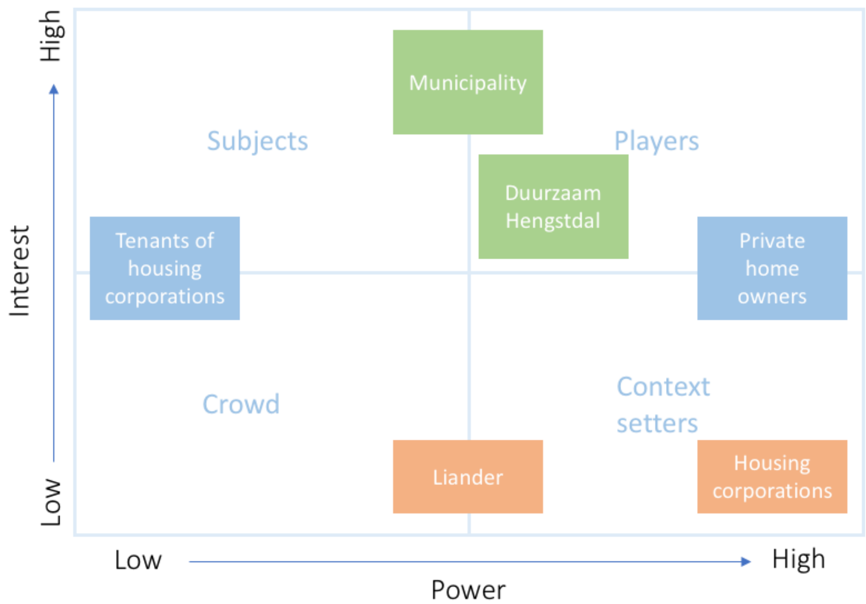

Figure 7. Overview of the main stakeholders in the Hengstdal case study. The stakeholders that are color-coded orange indicated that they were not interested to participate in the research conducted in this thesis. From the stakeholders that are color-coded blue it is not clear whether they would like to participate. The stakeholders that are color-coded green indicated that they were interested in collaborating with the research conducted in this thesis.

The position of each stakeholder in regard to the application of the PVE method will be discussed briefly:

1. Two **housing corporations** (*Standvast Wonen* and *Woningstichting De Gemeenschap)* own around 1900 houses in Hengstdal out of a total of 3,459 homes. The housing corporations indicated that they believe that consulting the tenants in the process is counter-productive, and does not fit in with the role the housing corporations play in relation to the tenants: they expect the housing corporation to make the decision and to coordinate it. The housing corporations are not willing to involve the **tenants** in the PVE method; they are identified as *context setters*. It is not clear whether the tenants would be interested in participating, but they have no power and are labelled as *crowd*.
2. **Liander**, the DSO of the neighborhood indicated that they were not interested in collaborating on the PVE method. They are identified in between *the crowd* and *context setters*
3. The energy transition officer of the **municipality of Nijmegen** was approached with the idea of implementing the PVE method for assisting the decision-making process on the transition of Hengstdal towards becoming a natural gas-free neighborhood. The energy officer indicated he was very interested in applying the PVE method. The municipality considered the PVE method to be interesting especially for **privately-owned houses**, for which the administration had no specific approach yet. However, during the meeting, the energy officer of the municipality pointed out that, in order to move forward with the PVE method, he first needed to get the citizens' initiative – **Duurzaam Hengstdal** – on board as well.
4. **Duurzaam Hengstdal** has been appointed by the municipality as the driving force behind the natural gas transition of Hengstdal. The meeting with Duurzaam Hengstdal also had a positive outcome, which led to the decision of choosing Hengstdal as the case study neighborhood for this research. Thus, both the **municipality** and **Duurzaam Hengstdal** indicated that they were very interested and have the power to implement the PVE method in Hengstdal. Therefore, both are labelled as *players*.
5. The **private home owners** possess the most power, because they make the decision whether to fill in the web tool of the PVE method or not. It is, however, unclear whether they are interested in participating in the experiment. The PVE method must be implemented first in order to determine whether they are *players* or *context setters*.

From the analysis of the stakeholders in Hengstdal the following conclusion can be made: the municipality and Duurzaam Hengstdal are the key stakeholders in the application of the PVE method to the Hengstdal case study, and their interests and power bases must be taken into account. However, the private home owners possess the most power, because the PVE method can only be applied if they decide to participate in the experiment. However, the PVE method must first be implemented in order to determine whether they are willing to participate.

The next step is to provide an analysis of the neighborhood that is the subject of the case study. Here, the key differences and similarities between Hengstdal and the Netherlands are identified with the aim of making it possible to interpret the results of the case study in a broader context. Additionally, the data gathered in this chapter will be used as input for the start-scenario for the ETM model, which will be discussed in Chapter 9.

6.3 The key socio-demographic variables in Hengstdal

The neighborhood Hengstdal is located in the east of the city of Nijmegen, as shown on the left of Figure 8, and was built between the 1920s and the 1950s after some ribbon had developed along the main roads. The district is located on the moraine (stuwwal) of Nijmegen and the terrain is slightly sloping (Nijmegen-Oost, n.d.). There are five areas in this neighborhood, which are all shown in Figure 8 on the right.

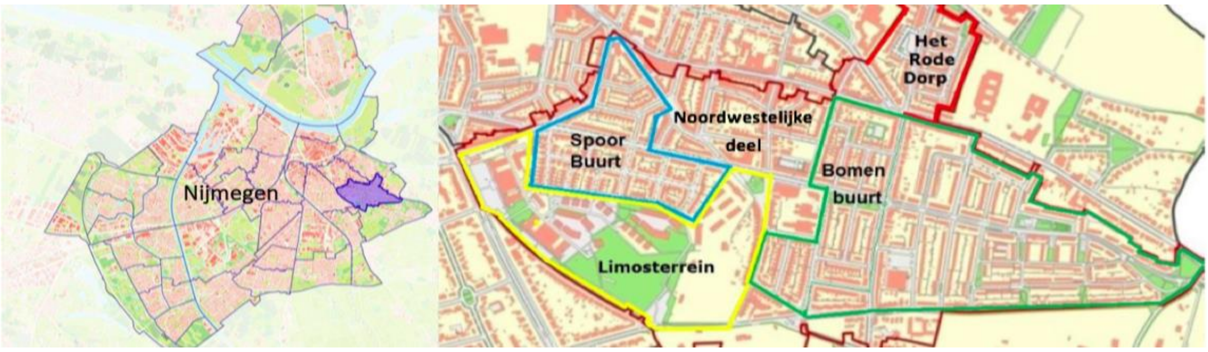

Figure 8. The map of the city Nijmegen with all the districts, Hengstdal is colored purple (l). The map of the district Hengstdal with the five main areas (r) (Duurzaam Hengstdal, 2016).

In this thesis, only the case study of Hengstdal will be conducted. Therefore, it is not possible to generalize the results of this research to other neighborhoods in the Netherlands. However, by highlighting key differences and similarities between Hengstdal and the Netherlands' average, the results can be interpreted in a broader context. A more detailed overview of the differences and similarities between Hengstdal and the Netherlands is provided in Appendix B.

The key differences and similarities between Hengstdal and the Netherlands are as follows:

1. In Hengstdal, 33% of the population is between 45 and 65 years old. Nationally, this percentage is 5% lower.

2. Hengstdal has more unmarried residents and more single-person households than the national average.
3. The distribution of ethnicities in Hengstdal is comparable to the distribution of ethnicities in the country.
4. On average, Hengstdal residents voted for a left party more often than the average Dutch voter.
5. Hengstdal has 31,5% more persons with a low income than the national average. Moreover, 5% of the neighborhood's population receives social assistance benefits (*Bijstand*), which is 3% higher than the national average.
6. In Hengstdal, 56% of the houses are owned by housing corporations, which is 26% higher than the average in the Netherlands.

The results from this research could, for example, show that the driving attribute for the choice of an alternative to natural gas for the residents of Hengstdal is the cost of the alternative, since 31.5% of the district's population has a low income. A hypothesis could be that cost is likely to be a more valuable attribute in a low-income neighborhood than in a high-income neighborhood. Thus, hypothetical relations between characteristics of the neighborhood and the evaluation of different attributes could be drawn and tested in future research.

6.4 The key aspects of the current energy system in Hengstdal

This paragraph will provide a structured overview of the energy system in Hengstdal. The Central Bureau of Statistics produces a structured overview of the energy system: the annual Energy Balance of the Netherlands.[3] The Energy Balance was used in this thesis to identify four key aspects of the energy system, which are production (1), distribution (2), installations (3) and consumption (4) (CBS, 2018A). A schematic overview is shown in Figure 9.

In order to provide a clear overview of the current energy system in Hengstdal, each of these four key aspects will be discussed. For each aspect – where possible – specific information will be provided about Hengstdal. Where relevant, information about the key characteristics of the national energy system will be provided.

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[3] In this thesis, the data set of the CBS *Energy balance sheet; supply, transformation and consumption*, is used. Data up to and including 2015 is final. Data for 2016 and further is still provisional. Therefore, only the data from 2015 is used.

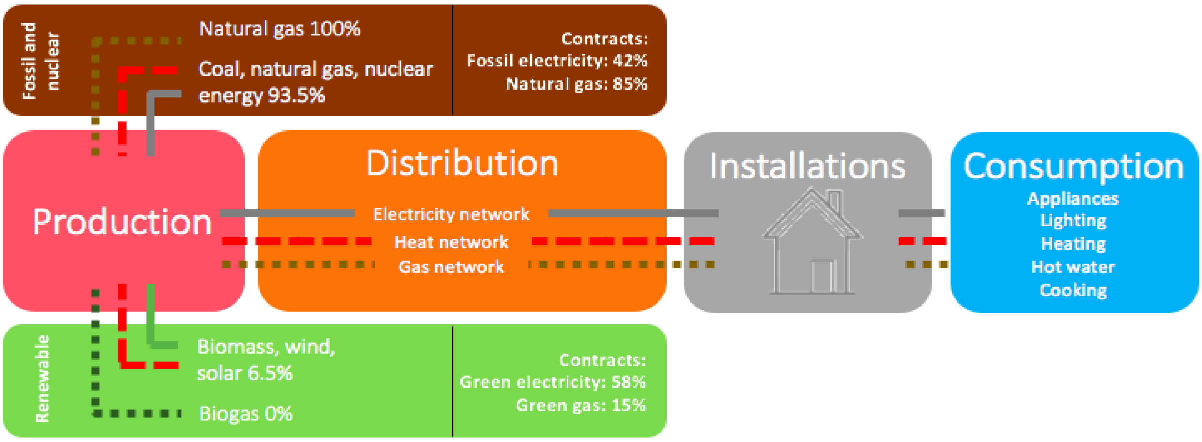

Figure 9. A schematic overview of the key aspects of the energy system for Dutch households – based on the Energy Balance of CBS (2018-1).

6.4.1 Energy production in Hengstdal

The is no specific information available about the production of energy in Hengstdal. However, as shown in Figure 10, Hengstdal is a district in Nijmegen with a very high population density – 8,380 residents / km² (CBS, 2015). The nearest energy plant is a coal-fired plant, also showed in Figure 10, owned by ENGIE, but this plant was closed at the end of 2015 (ENGIE, 2015). Therefore, there is no central production of energy through conventional energy plants in this district.

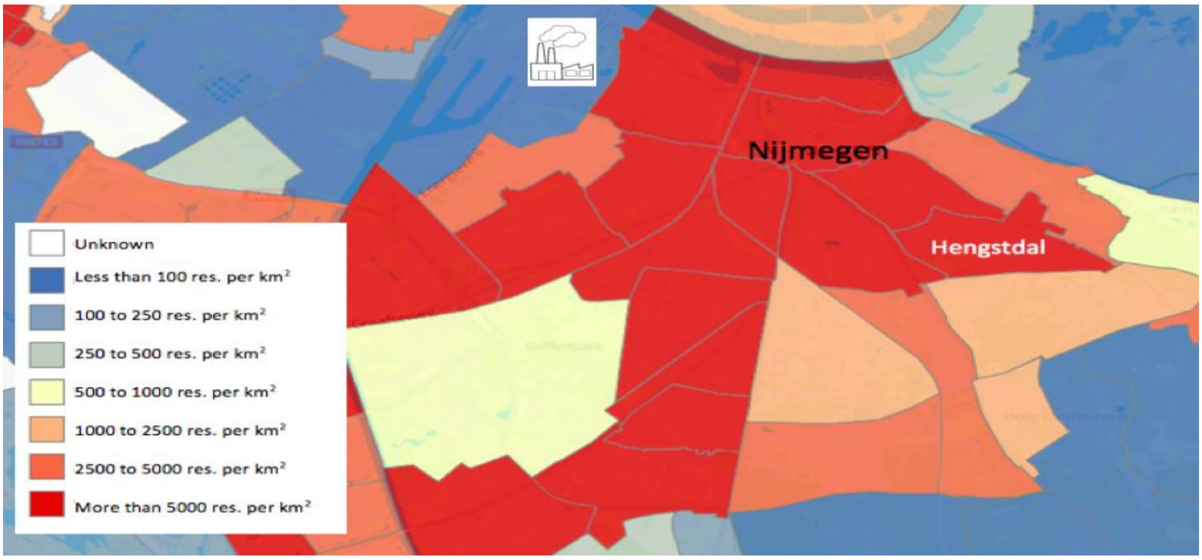

Figure 10. Map of the population density per km² in Nijmegen (CBS, 2015).

Wind turbines and solar panels also contribute to the production of electricity – used for example by heat pump. The closest wind park, with four wind turbines, is located on the Nijmegen territory, along the A15 motorway. The four wind turbines produce renewable energy for more than 7,000 households per year since the end of 2016 (Windpark Nijmegen-Betuwe, 2016). However, it is not clear how many solar panels are installed in Hengstdal.

It is assumed that the energy production in Hengstdal is similar to the ***indigenous production*** of the Netherlands. In 2015, the ***indigenous production*** – the extraction of energy commodities from nature – was equal to 2023 PJ (CBS, 2018A). There are four types of energy commodities produced in the Netherlands: fossil commodities (86.5%), renewable commodities (9.8%), nuclear commodities (1.9%) and non-renewable waste commodities (1.6%) (CBS, 2018A). On top of the production, ***imports*** of energy commodities in 2015 amounted 11379 PJ (CBS, 2018A). The majority of imports are fossil commodities: oil, coal, and natural gas – together 98.7% of the total (CBS, 2018A). Moreover, part of the energy produced in the Netherlands is exported: 10266 PJ, of which oil and petrol products (69%) and natural gas (18%) represent the largest share (CBS, 2018A).

When the primary sources used for the energy transformation and the losses that occur during this transformation are taken into account, only 6.5% of the energy consumed by households does not depend on the ***production*** of fossil energy or nuclear energy. Within this 6.5% of fossil-free consumption, biomass has the largest share with 5.1% (CBS, 2018A; CBS, 2018B).

6.4.2 Energy distribution of the energy through the networks of Hengstdal

Once the energy is produced, it needs to be distributed to the households. There are four major types of energy carriers available for Dutch households: natural gas, electricity, hot water and biomass. Natural gas, electricity and hot water have their own networks through which they are ***distributed***. Biomass can be converted into all desired forms of energy, such as liquid fuel, gas, solid fuel (pellets), electricity and heat. Consequently, it is either distributed by transportation or through the existing networks of the other energy carriers (CBS, 2018A).

In Hengstdal, there are only a gas network and an electricity network, managed by Liander. Around 1800 gas connections were built before 1985 (Liander, 2018). The gas network needs to be replaced every 40 years, which means that half of the gas network in Hengstdal will need replacement in the near future (Liander, 2018). The different ages of the networks in Hengstdal are shown in Figure 10.

Figure 11. The online gas map provided by Liander, shows the age of the gas network in Hengstdal. New pipes are pink, older pipes are light blue. The dark blue buildings are pipes of average age (Liander, 2018).

Moreover, in Hengstdal there is currently no district heating available. However, the municipality of Nijmegen does have a high temperature district heating network, which is managed by Nuon; it runs from the waste power plant ARN in Weurt – near Nijmegen – to the *Waalsprong* and *Waalfront*, as shown on the left of Figure 12. The waste incineration plant covers 94% of the heat demand; the remaining demand, mostly during peak hours, is covered by gas-fired auxiliary heat exchanges in the *Pieter Wiersma plant* (Nuon, 2016). In 2016, almost 4,000 homes were connected, but the ARN can potentially provide heat for up to 14, 000 households (Nuon, 2016). In the coming years, the existing district heating network will be expanded to the areas in the north-west of the city, as shown on the right of Figure 12: *Waalsprong* and *Stationsbuurt*. Additionally, possible expansions towards the south and east are being explored, and could include Hengstdal (CE Delft, 2016). Therefore, even if the neighborhood of Hengstdal does not currently have a district heating network, it has the potential to be connected to the existing district heating network in the future.

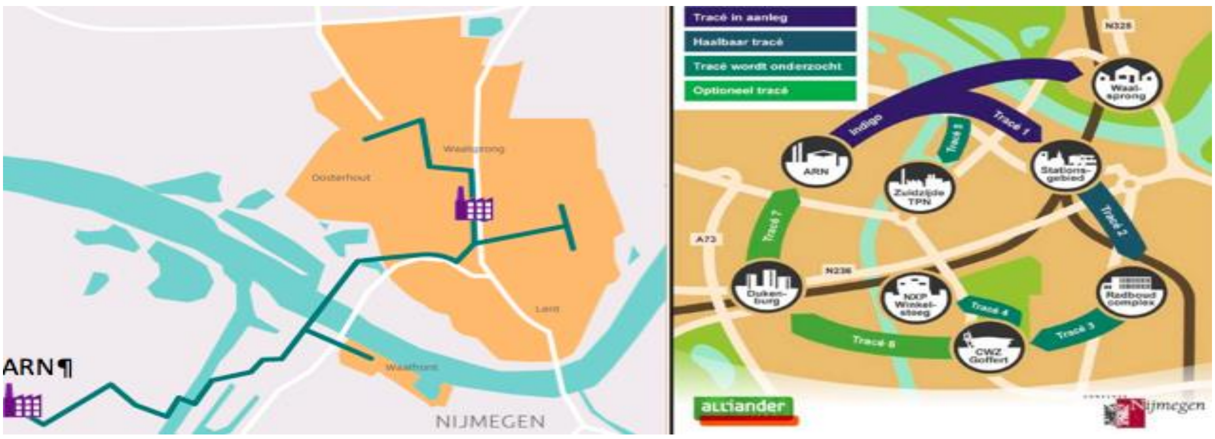

Figure 12. (l) The map shows the existing network for district heating in Nijmegen, with the waste power plant (ARN) as the source and the auxiliary heat plant Pieter Wiersma for peak hours (Nuon, 2016). (r) The map shows the planned extension of the district heating network (Liandon, 2014).

6.4.3 Different types of installations used in Hengstdal.

After the energy arrives to the houses, it is consumed through the use of appliances, lightning, space heating, hot water and cooking (Eurostat, 2018b). For the use of appliances and lighting, only electricity is consumed. However, for space heating, hot water and cooking, different types of **installations** can be used: the types of installations determine whether the households need gas, electricity, heat and or biomass (ECN, Energie-Nederland, & Netbeheer Nederland, 2015; Eurostat, 2018b). For cooking, the majority of Dutch households (64.9%) uses a gas cooker, which requires a connection to the gas network, while the rest uses an electric cooker that only requires a connection to the electricity network (Eurostat, 2018b).

There is no specific information available about the installations in Hengstdal. However, due to the fact that there is currently no district heating network in the neighborhood, it can be assumed that district heating is not an option for hot water and space heating in Hengstdal.

For heating and hot water, there are several installations available. As mentioned before, 91.5% of households have a connection to the gas network (ECN, Energie-Nederland, & Netbeheer Nederland, 2016). In particular:

- 82.1% has central heating with an individual boiler – 89% of these are high-efficiency boilers (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).
- 2.9% has local heating on natural gas (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).
- 6% has block heating – a smaller version of district heating – on natural gas (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).
- 0.5% has a connection to a district heating network with a separate connection to the gas network for cooking (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).

Figure 13 provides an overview of all the different types of installation for heating and hot water in the Netherlands. Due to the fact that the share of houses with central heating and an individual boiler is significantly higher than the rest, it is omitted from the graph, in order to make it possible to compare the shares of the other alternatives. Only 6.2% of the available installations for space heating and hot water are completely independent from natural gas (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).

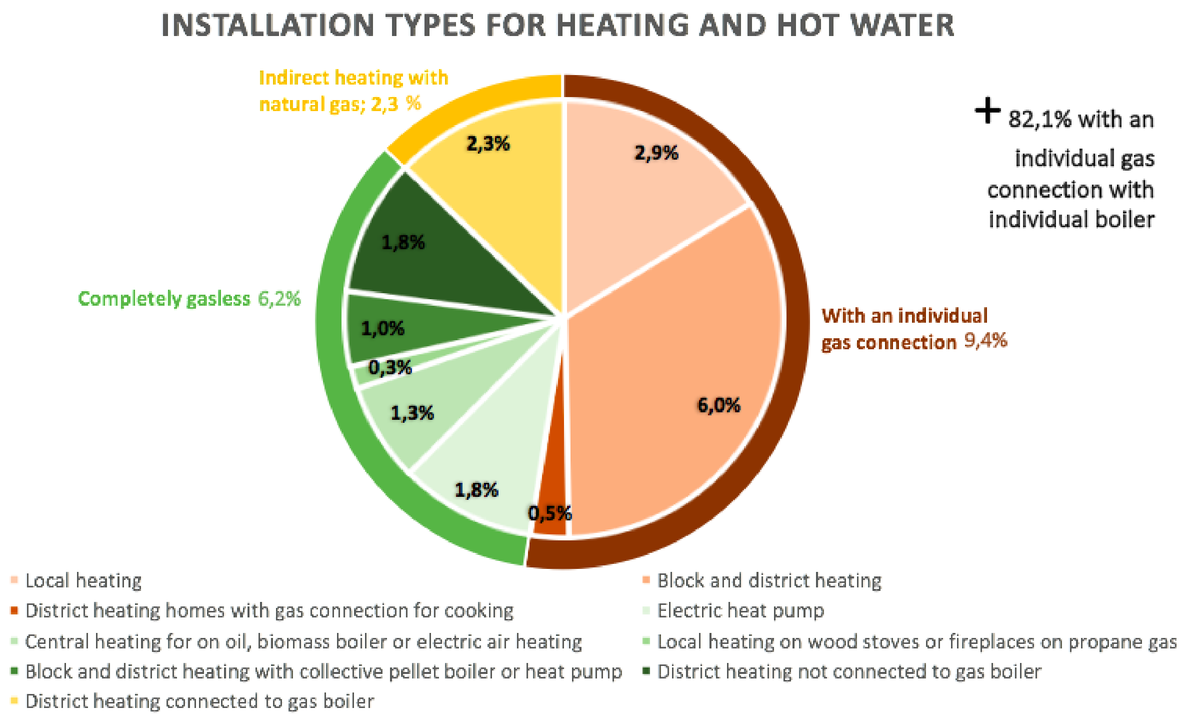

Figure 13. Households in the Netherlands mainly have an individual gas connection and an individual boiler (82.1%). Only 6.2% that are completely gasless. There rest is divided in several options that are either directly or indirectly making use of natural gas for heating and hot water (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).

To summarize, all houses use electricity for appliances and lighting. Additionally, most installations for hot water and space heating are high-efficiency boilers for central heating. There are other installations, such as heat pumps or pellet stoves, but their shares are significantly lower. Lastly, two thirds of the households use gas for cooking, while one third uses electricity. Thus, it can be concluded that the majority of installations still require a connection to the natural gas network.

6.4.4 Energy consumption of an average household in Hengstdal

In this paragraph, a short overview is given of the **energy consumption** of a household in Hengstdal and is compared to the energy consumption nationally. An average house in Hengstdal uses 2380 kWh of electricity and 1190 m^3 of gas per year (CBS, 2015). This is lower than the Dutch average with a consumption of 2966 kWh of electricity and of 1432 m^3 gas. The comparison is shown in Figure 14 (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).

There is no specific information about the energy contracts in Hengstdal. However, 58% of the Dutch households has a contract for green electricity and 15% to the Dutch households had a contract for green gas (Milieu Centraal, 2015; HIER Klimaatbureau, 2016). However, most green electricity is bought with cheap foreign GO's, which is not increasing the indigenous production of renewable electricity (Milieu Centraal, 2015). Additionally, due to the current lack of available biogas, people with a contract for green gas actually still use natural gas – only the negative environmental impact of this gas is compensated by contributing to climate-friendly projects. Only contracts that sell renewable electricity generated by Dutch solar or wind power, or farms that sell their biogas directly to their consumers are actually increasing the demand of Dutch households for renewable energy in the Netherlands. (HIER Klimaatbureau,2016).

Lighting is the biggest electricity consumer with 390 kWh per year; televisions, with 270 kWh per year, and fridges, with 250 kWh per year, are second and third (ECN, Energie-Nederland, & Netbeheer Nederland, 2016). The largest consumer of natural gas in a house is the high-efficiency boiler, which consumes around 1400 m^3 of gas per year (ECN, Energie-Nederland, & Netbeheer Nederland, 2016). Cooking consumes 37 m^3 of gas annually (Milieu Centraal, 2018a).

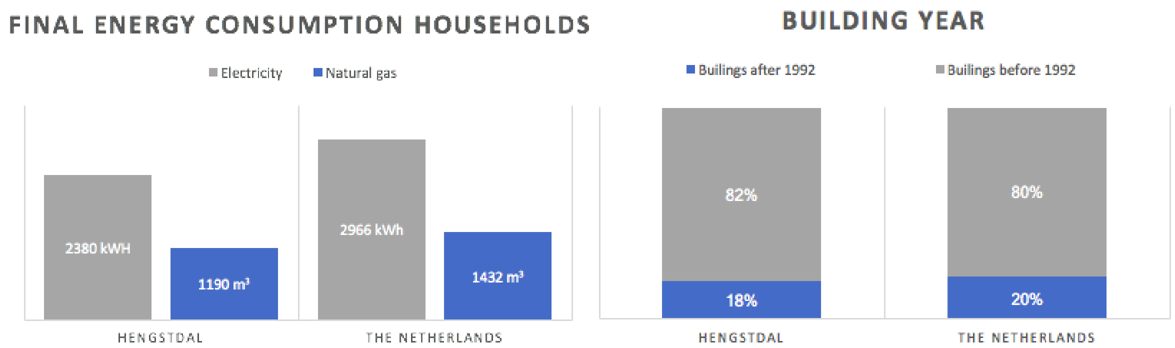

Figure 14. (l) The final consumption of electricity and natural gas of an average household in Hengstdal and in the Netherlands (ECN, Energie-Nederland, & Netbeheer Nederland, 2016). (r) The distribution of houses built before 1992 and after 1992 (CBS, 2015; Kadaster 2018).

Electricity consumption has only started to decrease in 2012. The consumption was around 3250 kWh per house that year, while in 2015 it was reduced to 2966 kWh (CBS, 2015). This decrease is mainly a result of the fact that appliances are becoming more efficient (ECN, Energie-Nederland, & Netbeheer Nederland, 2016). Gas consumption, instead, has been decreasing already for 20 years, as a consequence of energy-saving measures such as insulation (ECN, Energie-Nederland, & Netbeheer Nederland, 2016).

The building year of a house is a good indication of how well it is insulated. Figure 14 also shows, in the graph on the right, the distribution of houses built before and after 1992. On average, houses built before 1992 do not have sufficient insulation. Conversely, houses built after 1992 have well insulated roofs, façades and floors (Milieu Centraal, 2018b). In the Netherlands, 80% of the houses were built before 1992 (CBS, 2018A). In Hengstdal, there is a similar distribution: out of the 3454 houses in total, 82% were built before 1992[4] (CBS, 2015; Kadaster, 2018).

The effects of insulation can be illustrated as follows. A single-family house without insulation loses a large amount of heat through the windows, façade, roof and floor and consumes at least 3300 m^3 of gas per year for heating (Milieu Centraal, 2018b). A similar well-insulated house only needs 600 m^3 of gas for heating (Milieu Centraal, 2018b). Insulation can save households up to 1600 euros per year (Milieu Centraal, 2018b). Another energy saving measure was the introduction of energy labels, which show how environmentally efficient a house is. Label A+ – the highest – indicates a consumption of less than 0.7 GJ per m^2 per year, while label G – the lowest – indicates an energy consumption of over 2.9 GJ per m^2 per year. The label aims at providing a quick indication of the energy consumption of a house. Around 2.9 million houses have been provided with an energy label, as of 1 January 2016 (Compendium voor de Leefomgeving, 2016). Approximately 9% of the houses has label A, 16% label B, 31% label C and 23% label D, while the remaining 21% has label E or worse. (Compendium voor de Leefomgeving, 2016).

Figure 15. The map shows the energy labels in Hengstdal provided by the Energie Atlas (Energie Atlas, 2018). The average energy label in Hengstdal is E. (WoonConnect, 2017).

The average energy label of Hengstdal is E, which is lower than the average label C in the municipality of Nijmegen (WoonConnect, 2017). In Figure 15, the Energie Atlas shows a detailed map of the distribution of energy labels in Hengstdal (Energie Atlas, 2018).

[4] The data base that is used for Hengstdal is called *CBS in uw buurt*, and this database only makes a distinction between houses built before or after the year 2000. In Hengstdal, 518 houses were built after 2000. The Kadaster is then used to identify the houses built between 1992 and 2000, which were an additional 106. Together, this is 624 houses built after 1992 –out of 3454 houses – which is equal to 18%.

To summarize, Hengstdal does not produce energy locally. It is connected to the electricity network and gas network, which are managed by Liander. About half of the gas connections will need replacement in the next few years – one of the reasons why Hengstdal was selected for the energy transition. There is no district heating in Hengstdal but, due to the sufficient capacity of the existing district heating network in Nijmegen, it could be possible to connect Hengstdal to the district heating network in the future. Lastly, while the average energy consumption of a household in Hengstdal is lower than the national average, houses in Hengstdal have an average energy label E, lower than the Dutch average that is between C and D. In summary, houses in Hengstdal have poorer insulation but nevertheless consume less energy than the average Dutch house. A possible explanation could be that, due to the very high density of households in Hengstdal, houses in the district might be smaller on average and, therefore, consume less energy.

3. Design follow-up qualitative questions

The information gathered in this paragraph is used to execute step 3 of the PVE method. The following five relevant background variables were identified that could be of influence on the preferences of the citizens on each alternative:

- The type of energy contract influences the share of renewable energy.
- The type of installation determines what type of energy (renewable or not) is consumed, which means that it could influence the share of renewable energy.
- Then, the better the insulation of a house, the less amount of gas is consumed. Two variables which are good indicators for the level of insulation are:
    - The building year of the house;
    - The energy labels.
- The type of cooker – gas or electric – can also determine whether a house needs natural gas.

This information was used to design the follow-up questions to be included in the web tool (step 3 of the PVE method). The exact composition of each follow-up question can be found in Appendix C.

Now that a clear overview of the current context in which the transition of the neighborhood to zero natural gas use takes place has been provided, the next step is to determine the possible alternatives to natural gas. This will be discussed in next chapter.

7 ALTERNATIVES FOR NATURAL GAS

The main objective of this chapter is to provide a structured overview of the currently available alternatives for natural gas which could be implemented in Hengstdal. This is important, because in order to be able to calculate the effects of each alternative on the attributes with ETM, the alternatives first must be determined. Moreover, the information about the alternatives gathered in this chapter will be used for the development of the different energy scenarios in Chapter 9.

The first step is to show how information about the different alternatives is currently structured, which is discussed in Paragraph 7.1. Then, a different approach in structuring these alternatives, based on the analysis of the energy system in Chapter 8, is proposed in Paragraph 7.2. Subsequently, the Chapter end with a structured overview of the currently available alternatives for natural gas in Paragraph 7.3.

7.1 Information provision of alternative solutions

A survey conducted by the VEH, mentioned in the introduction, shows that 40% of the homeowners indicate that they do not have enough information and, therefore, do not understand the matter of energy transition well enough to make an informed choice about which alternative heating source to choose (2017). While most of them agree with the fact that neighborhoods must become natural gas-free, they often do not have a preference for a specific alternative, due to their lack of understanding on the topic (VEH, 2017).

The survey also shows that citizens trust consumer organizations and the government the most when it comes to information about the energy transition (HIER Klimaatbureau, 2017). Consumer organizations and the government aim at assisting the citizens in this transition towards natural gas-free houses by providing information through their websites about alternatives for natural gas. A brief overview of the provided suggestions on these websites is given in Table 5.

SOURCES	ALTERNATIVES FOR NATURAL GAS
Rijksoverheid, 2018c: The Dutch Government	Solar panels, geothermal heat, heat pumps, electric cooking, cooking on induction, ceramic hobs, pellet stoves, biomass boilers, and solar water heaters
Milieu Centraal, 2018c: Established in 1998 by the former Ministry of Environment as an	Renewable energy, biogas, solar boilers, heat from the soil stored in the summer, heat from deeper layers, heat

independent body that provides independent advice on environmental friendly behavior.	pumps, district heating, insulation of the façade, insulation of the floor, HR ++ glass.
HIER Verwarmt, 2018: Foundation, the only social organization in the Netherlands that focuses entirely on the subject of climate change	Floor insulation, roof insulation, cavity wall insulation, insulation of the inside or outside façade, HR ++ / +++ glass, cooking on induction, solar panels, a (hybrid) heat pump, choose green gas and green electricity.
Warmte Koude Zuid-Holland, 2017: An alliance consisting of energy and heat network companies, the financial sector, greenhouse horticulture, municipalities, regions and the province of Zuid-Holland	Cooking on induction, floor insulation, HR ++ glass, heat pumps, district heating.
RVO, 2018b: Government service for the entrepreneurial Netherlands.	High temperature district heating, renewable gas, biomass, a pellet stove, low temperature district heating, collective heat pump, geothermal heating.

Table 5. An overview of suggested alternatives for natural gas, divided per information source

Table 5 shows that there is a broad range of alternatives offered, but not in a very structured way. One of the problems with the information offered online is that it suggests alternatives which are only applicable on specific aspects of the energy system.

For example, a suggestion is to use alternative energy sources, ***produced*** by renewable energy, or opting for green contracts or installing solar panels (HIER Verwarmt, 2018; Milieu Centraal, 2018c). However, some of them also recommend households to connect to a ***network*** for district heating (Milieu Centraal, 2018c; RVO, 2018b; Warmte Koude Zuid-Holland, 2017) or suggest changing natural gas for biogas (Milieu Centraal 2018-3; RVO, 2018b). Additionally, several suggestions advocate the use of different ***installations***, for example cooking on induction (Rijksoverheid, 2018c; HIER Verwarmt, 2018; Warmte Koude Zuid-Holland, 2017), or using a pellet stove or heat pump for heating (Milieu Centraal, 2018c; RVO, 2018b). Lastly, it is pointed out that good insulation of walls, windows, roofs and floors will significantly lower the energy ***consumption*** (Milieu Centraal 2018-3; HIER Verwarmt, 2018; Warmte Koude Zuid-Holland, 2017).

Finding a sustainable alternative for the whole energy system, therefore, can only be achieved by combining alternatives for each aspect of the energy system. Consequently, there will be a large number of compositions of alternatives available to choose from. However, the higher the number of alternatives, the more difficult it will become to provide a clear overview about each alternative.

Moreover, not all combinations are feasible. The type of ***installation*** determines whether a household needs a connection to the gas **network**, to the electricity **network**, to the heat **network**, or whether it runs on biomass (ECN, Energie-Nederland, & Netbeheer Nederland, 2016). To illustrate this, if a household wants to use heat from an incinerator for space heating, it must be connected to the network for district heating. While if it is decided to use a heat pump, a connection to the electricity network is sufficient.

Furthermore, not every combination of alternatives is desirable. For example, if a heat pump is installed in a house that is poorly insulated, it will not have the capacity to raise the temperature to a comfortable level. Therefore, a heat pump should only be installed in combination with sufficient insulation (Milieu Centraal, 2016).

Thus, a broad range of alternatives are offered in an unstructured way, which makes it difficult for citizens to choose an alternative. Therefore, in this thesis, an approach is suggested to structure the alternatives, in order to assist citizens in their choice.

7.2 Approach to structure the alternatives

The approach that is suggested to structure the alternatives is based on three assumptions, of which the first is based on research, and the last two on altered methodological steps in Chapter 5.

First of all, the main aspects of the energy system introduced in the previous chapter – energy production, networks, installations and consumption – are suitable to make a distinction between different types of alternatives and, when considered together, these aspects allow to build different alternatives which are suitable as substitutes for natural gas.

Second, these distinctions are also in line with the strategy of Duurzaam Hengstdal: the 'no regret' strategy. According to their strategy, the focus is first on lowering the energy consumption through insulation and on convincing households to sign more green energy contracts. Afterwards, the focus would shift towards replacing installations (Duurzaam Hengstdal, 2017). It should be noted that – as explained before – the types of installations determine whether households need gas, electricity, heat or biomass. Therefore, choosing a specific installation is necessarily linked to choosing the relevant network. This link, however, is not taken into account in the Duurzaam Hengstdal's strategy.

Lastly, only well-established alternatives for natural gas should be considered (Duurzaam Hengstdal, 2017). In line with this demand and the government's advice, the following three types of alternatives for natural gas will be considered: district heating networks, all electric, and biogas (RVO, 2018b).

Based on these assumptions, citizens can make three main choices about the composition of the alternatives, which is schematically shown in Figure 16.

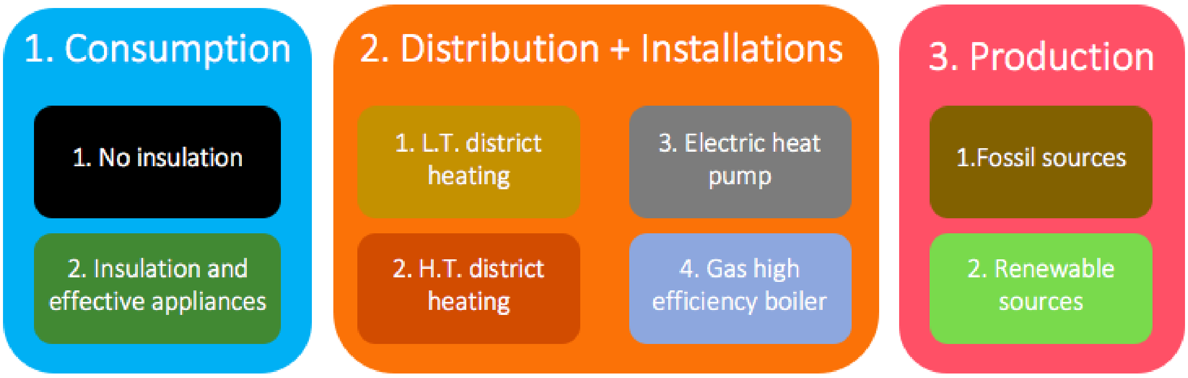

Figure 16. Schematic overview of the three main choices about the composition of the alternatives that the citizens can make.

The figure shows that citizens can make three choices about:

1. Whether or not to lower the energy consumption of both; the heating demand through insulation; and the electricity demand through efficient appliances and lightning.
2. Whether or not to choose an alternative installation and the according network:
   a. A high efficiency boiler, which means that connection to the natural gas network remains in place.
   b. District heating, which requires a connection to the heating network:
      i. With normal radiators, high temperature district heating is required;
      ii. With floor heating, low temperature district heating is sufficient;
   c. An electric heat pump, which only requires a connection to the electricity network;
3. Whether or not to choose locally produced renewable energy:
   a. Residual heat from the ARN waste power plant for district heating with either normal radiators or floor heating;
   b. Locally produced wind and solar energy for the electrical heat pump;
   c. Biogas for the high efficiency boiler.

Each combination of these three choices will lead to a different alternative. There are sixteen possible alternatives in total: citizens can choose whether they want a fossil or a renewable energy source, whether they want insulation or not, and can choose among four different types of networks with their relative installations (2x2x4 = 16 options).

It should be pointed out that some of these combinations might not be desirable, e.g. the combination of a heat pump without any insulation. These options are included nevertheless, because the idea of the PVE method is to provide the residents of Hengstdal with an overview of the impact of the considered alternatives on all important values regarding the energy transition. In this way, residents of Hengstdal can decide for themselves whether an alternative is desirable or not.

7.3 Structured overview of the alternatives for natural gas

As mentioned, the three choices that residents of Hengstdal face are: a) increasing insulation or not; b) choosing among four types of networks and installations; and c) choosing a renewable or a fossil energy source.

4. Determine the alternatives

Together they led to the composition of 16 different alternatives, see Table 6, which is step 4 of the PVE method:

1. High efficiency boiler with natural gas without insulation	9. Normal radiators connected to the high temperature district heating network with heat from a gas-fired plant without insulation
2. High efficiency boiler with biogas without insulation	10. Normal radiators connected to the high temperature district heating network with heat from a waste power plant without insulation
3. High efficiency boiler with natural gas with insulation	11. Normal radiators connected to the high temperature district heating network with heat from a gas-fired plant with insulation
4. High efficiency boiler with biogas with insulation	12. Normal radiators connected to the high temperature district heating network with heat from a waste power plant with insulation
5. Heat pump that runs on fossil power and without insulation	13. Floor heating connected to the low temperature district heating network with heat from gas-fired plant without insulation
6. Heat pump that runs on wind and solar power and without insulation	14. Floor heating connected to the low temperature district heating network with heat from a waste power plant without insulation
7. Heat pump than runs on fossil power and with insulation	15. Floor heating connected to the low temperature district heating network with heat from gas-fired plant with insulation
8. Heat pump that runs on wind and solar power with insulation	16. Floor heating connected to the low temperature district heating network with heat from a waste power plant with insulation

Table 6. An overview of the 16 different alternatives used in this PVE method.

The most important features of the three choices are discussed briefly in the next paragraphs.

7.3.1 Lowering the energy consumption of the households in Hengstdal

The first choice is to try to lower the households' energy consumption in Hengstdal as much as possible. To reach this goal, houses should be insulated to energy label A and the most efficient appliances and lightning should be bought.

WoonConnect conducted a study, commissioned by the municipality of Nijmegen, on the current energy consumption of households in Hengstdal, and on what the effects could be if all houses were insulated to energy label A. Houses receive energy label A when they have insulated cavity walls, roofs, floors and HR++ windows (Milieu Centraal, 2015). As explained before, the building year of a house is a good indication of how well it is insulated. Houses built before 1992 have – on average – insufficient insulation, while houses built after 1992 are on average well insulated. The WoonConnect study shows that insulating houses which are built before 1992 results in a 63% reduction of annual energy consumption. Insulating houses that are built after 1992 to label A, instead, results in a 18% reduction of annual energy consumption (WoonConnect, 2017).

All household appliances are also labeled with an energy label, as required by the European Union. The label goes from the letters A +++ to D, where A +++ is the most efficient level. The law stipulates which information must be displayed on the energy label. In order to obtain this information, standard measurements take place. As a result, the energy efficiency of different devices can be compared. As regards lighting, LED lights are the most efficient choice (Consumentenbond, 2017). The web tool developed for this thesis gives citizens the choice about whether or not to insulate their house: when citizens choose insulation, they automatically choose also the most efficient appliances (A +++). Therefore, respondents do not have the option to choose specific appliances with different energy efficiency levels, but can only choose whether they want insulation or not.

7.3.2 An alternative installation with network:

The second choice is between four types of installation with their according networks: district heating, (with normal radiators or floor heating), an electric heat pump or a high efficiency boiler.

The previous chapters have already explained that different installations require a connection to different networks, and thus the choice of a specific installation implies the choice of its relative network. Only the workings of an electric heat pump require some additional explanation. There are two kinds of heat pumps: air heat pumps and ground heat pumps. These two types of pumps have different costs. As WoonConnect explains, an air heat pump is always cheaper than a ground heat pump, even though it has the same level of efficiency. For this reason, it was decided to include only air heat pumps as a viable choice in the web tool.

7.3.3 Locally produced renewable energy in Hengstdal

The third choice is between local renewable energy sources or fossil energy sources. There are three options for locally-produced renewable energy in Hengstdal: residual heat from the ARN waste power plant (suitable for district heating with either normal radiators or floor heating), locally-produced wind and solar energy (for electric heat pumps), or biogas (for high efficiency boilers). As explained, each renewable energy source is linked to a specific network, which in turn is linked to the use of specific appliances. Each option for a renewable energy source will be analyzed separately.

7.3.3.1 Residual heat from the ARN waste power plant

Residual heat from the ARN waste power plant near Nijmegen can be used to produce heat in a sustainable way. The incineration of waste causes heat to be released. Part of that energy is used by ARN for the production of green electricity. The remaining energy heats the water for the district heating network. In this way, energy production does not depend on fossil fuels and is therefore a renewable energy source. (Nuon, 2016). In 2016, almost 4,000 homes were connected, but the ARN waste power plant can potentially provide heat for up to 14, 000 households (Nuon, 2016). In the future, also Hengstdal could be connected to the network.

7.3.3.2 Locally produced wind and solar power

The air heat pump alternatives for natural gas consume electricity. In order to have a sustainable heat source, renewable electricity should be used. Locally produced wind and solar power can be used to meet the electricity demand. Only contracts that sell renewable electricity generated by Dutch solar or wind power – or farms that sell their biogas directly to their consumers – are actually really increasing the production of renewable energy in the Netherlands (Milieu Centraal, 2015). One potential renewable electricity source for Hengstdal could be the additional wind turbine in the wind farm Nijmegen-Betuwe, which is currently being discussed (RVO, 2016).

The Energy Atlas can be used to explore the possibilities of the production of local solar power. Figure 17 shows a map of Hengstdal, provided by the Energy Atlas, that indicates whether houses are suitable for solar panels. The areas marked in purple are protected property of the city, which means that they are not allowed to put any solar panels on the roof. However, the other areas show plenty of potentially suitable roof tops.

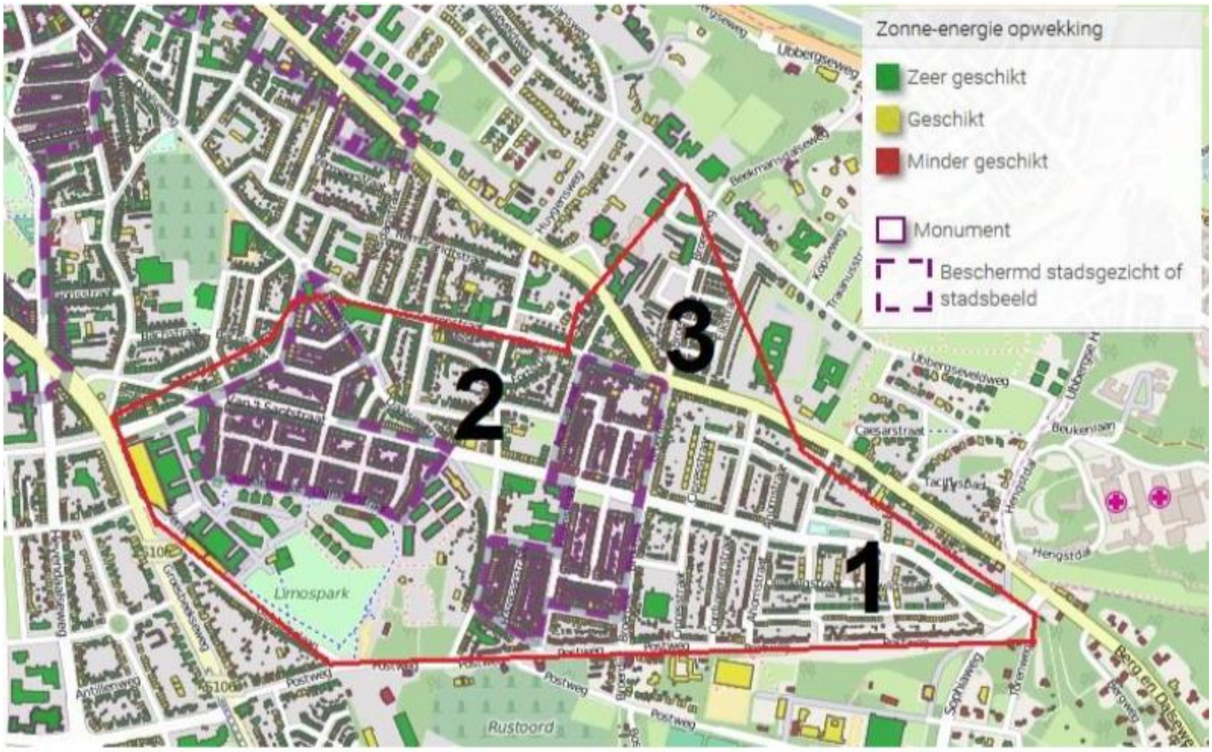

Figure 17. A map of Hengstdal that indicates whether houses are suitable for solar panels. The areas marked in purple are protected property of the city, which means that they are not allowed to put any solar panels on the roof.

7.3.3.3 Biogas

Biogas is the last option for a renewable energy source. The indigenous production of biogas was 13.7 PJ in 2015, but only 0.7 PJ remained available for consumption. At the moment, households only use biogas indirectly, through their consumption of electricity and heat produced by biogas, which only accounts for 0.2% of the total energy usage of households (CBS, 2018A). However, PBL expects a significant growth in the production of biogas for the coming years, coupled with an even bigger increase in its demand. Given the likelihood that biogas will remain scarce in the future, PBL advises to only use biogas in sectors where there are no other options, such as in aviation or inner cities that are unable to choose different alternatives for natural gas (PBL, 2014).

Now that the alternatives are determined, the next step is to select the attributes. This will be discussed in the next chapter.

8 THE IMPORTANT VALUES REGARDING THE ENERGY TRANSITION

The key objective of this chapter is to present an overview of the attributes of the PVE method, which is step 5 of the PVE method. The attributes must reflect the most important values regarding the transition of Hengstdal according to its residents. Therefore, the most important values must be identified first.

The problem is that no research has been conducted – so far – on identifying these important values for the residents of Hengstdal. However, a study on the most important values regarding the energy transition in the Netherlands according to Dutch citizens – commissioned by the Ministry of Economic Affairs – has recently be conducted by Motivaction (2016). The results of this study are used in order to determine what the most important values are and select 8 attributes.

The study of Motivaction examined the support of the Dutch population for various CO_2-reducing alternatives (Motivaction, 2016). Various trade-offs regarding CO_2-reducing options were presented to the citizens, in order to investigate which values are key when participating in the energy transition in the Netherlands. CO_2-reducing options are often associated with conflicting values and trade-offs (Motivaction, 2016). To illustrate this, one of the trade-offs used was: *Either there will be more nuclear power plants in the Netherlands – which take less space from Dutch landscape but pose more risks to public health in case of a meltdown – or wind turbines and solar panels will be placed, which take more space from the landscape, but pose less risk for public health* (Motivaction, 2016).

From the selected trade-offs, it becomes clear that there are ten values that Dutch citizens want to see guaranteed in their energy system (Motivaction, 2016). The research of Motivaction does not provide a precise definition for these values, there are only further explanations given on the recurring trade-offs between the main values. This thesis will complement the Motivaction's research by providing short explanations about what the values actually entail, at least for those cases where the name of the values is not self-explanatory. The ten most important values that Dutch citizens want to see guaranteed in their energy system are[5] (Motivaction, 2016):

- **Affordability**; the costs of alternatives, which are often regarded as unaffordable.
- **Availability**; Dutch citizens want to have no black-outs.
- **Autarky**; Dutch citizens value to be independent from energy imported from other countries.

[5] The original Motivaction study is in Dutch, so the names of the values are translated to English.

- **Positive impact on economy and employment.**
- **Preservation of landscape quality.**
- **Comfort**; Dutch citizens want to have an acceptable room temperature.
- **Ecology**; the degree of sustainability of the various alternatives.
- **Nuisance**; Dutch citizens believe it is important that the local residents do not suffer any nuisance, e.g. in terms of noise pollution due to installations.
- **Innovation**; half of the Dutch citizens consider valuable the idea that the Netherlands could become a leader in the field of sustainable energy; the other half does not see this as a reason to move away from fossil fuels.
- **Safety**; Dutch citizens have doubts the safety of nuclear energy and underground CO_2 storage.

These 10 values – identified by Motivaction – will be used as input for the selection of the attributes, which is step 5 of the PVE method. However, as explained in Chapter 5, no more than eight attributes should be selected, which means that only eight of the identified values will be used. The values to be disregarded were selected as follows. First of all, half of the citizens do not consider **Innovation** as important (Motivaction, 2016), and thus this value will be disregarded in this research. Second, the values **Ecology** and **Preservation of landscape quality** are slightly overlapping, considering that alternatives with a high level of CO_2-emissions also have a negative impact on the preservation of the landscape quality in the long-term. These two values are not exactly the same, but due to the constraints of the PVE-method, it is decided that the value **Ecology** is also indirectly representing the value **Preservation of landscape quality**, which is therefore omitted.

5. Select the attributes

The remaining eight values will be used as attributes in this research: affordability, availability, autarky, comfort, nuisance, ecology, safety and employment impact. Which is step 5 of the PVE method.

Now that the attributes – based on most important values regarding the transition of Hengstdal – are selected, the next step is to calculate the effects of each alternative on the attributes. This will be discussed in the next chapter.

9 EFFECTS OF ALTERNATIVES ON THE CONSTRAINT AND ATTRIBUTES

The key goal of this chapter is to provide an overview of the effects of each alternative on the constraint and attributes. This is important because, in order to provide a clear overview of all the effects of each alternative in the web tool, first all the effects must be calculated, which is step 6 of the PVE method.

Consequently, this requires calculations on the effects of 16 alternatives on both the 1 constraint and the 8 attributes, which result in a total of 144 calculations (16 x 9). In order to conduct these calculations, an existing model – the Energy Transition Model[6] (ETM) – was used. The ETM is an independent, comprehensive and fact-based energy model that is used by governments, corporations, NGOs and educators to evaluate energy scenarios for many different projects. The ETM has been developed by Quintel Intelligence (2015).

Using energy scenarios to calculate the effects of each alternative for the PVE method is a new application of the ETM, which Quintel Intelligence was keen to explore. In Appendix D, an overview is given of how the ETM works and which scenarios are created for the PVE method.

The ETM can only be used to calculate the effects of each alternative on the following constraint and attributes: renewability (0), affordability (1), availability (2), autarky (3), employment (4) and ecology (7). An overview of how the attributes are calculated will be provided in Paragraph 9.1. For the remaining three attributes – safety (5), comfortability (6) and nuisance (8) – literature is used to estimate the effects of each alternative, which will be discussed in Paragraph 9.2. Paragraph 9.3 provides an overview of all the effects of each alternative on the constraint and attributes.

9.1 Calculation values attributes with ETM

The first step is to explain how the effects of each alternative on the constraint and attributes – renewability (0) and attributes affordability (1), availability (2), autarky (3), employment (4) and ecology (7) – are calculated.

[6] The ETM is available on the following website: https://beta-pro.energytransitionmodel.com/

9.1.1 Renewability (0)

The constraint renewability is defined as the percentage of renewable energy used to fulfill the final energy consumption of the households for each alternative. In units, this is the percentage of renewable energy. The ETM calculates the percentage of renewables consumed by a household, so it is not needed to make any further calculations. Figure 18 shows the breakdown of the final energy demand for the alternative with high temperature heating, wind and solar power and insulation. The graph on the right shows that – with this alternative – the percentage of renewable energy in 2045 would be close to 60%.

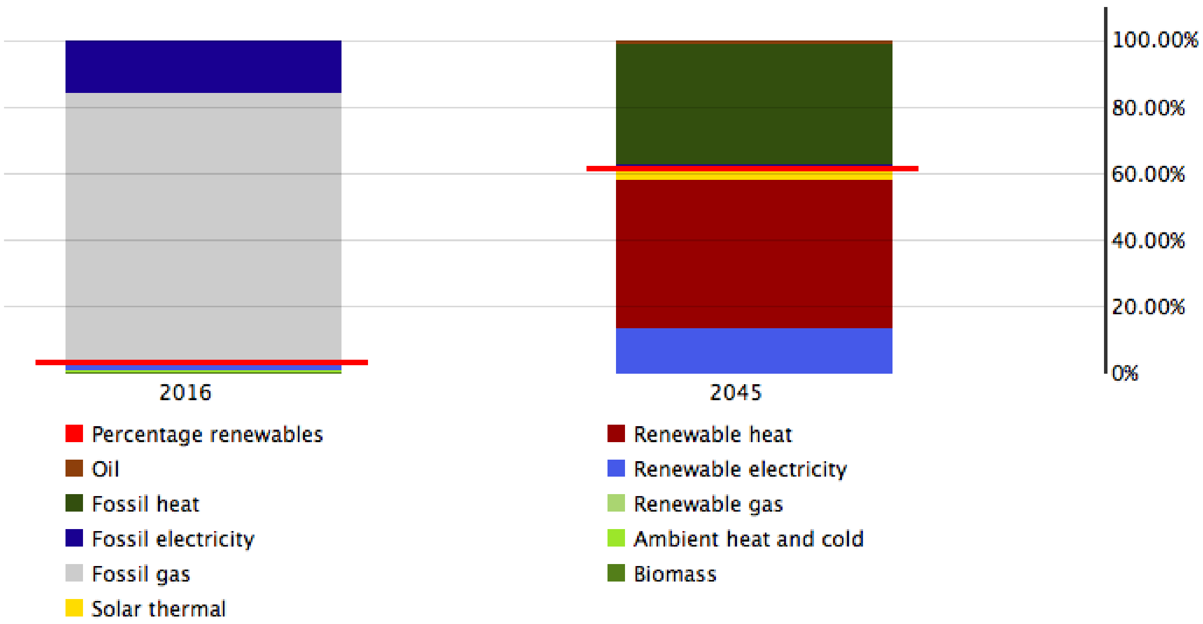

Figure 18. The ETM produces a graph that shows the breakdown of the final energy consumption of households in 2016 and 2045.

An overview of the effects of each alternative on the constraint renewability can be found in Table 9 of Paragraph 9.3.

9.1.2 Affordability (1)

The attribute affordability is defined as the average annual cost per household for each alternative. In units, this is: €/year/household. In this way, each person can decide for himself or herself how he or she perceives the affordability of these costs for each alternative. The ETM calculates the average annual costs for a household by adding up the following four aspects:

1. Use of fuels per year, which is multiplied for the price of these fuels;
2. Investment and financing costs in all technologies for the production of electricity and heat – divided by the technical lifespan of each type of devices;
3. Annual maintenance costs of the networks;

4. Investment costs for flexibility (batteries, power-to-heat installations, etc.) – also divided by the technical lifespan of each type of device. Then, these costs are divided by the number of citizens in the district.

Additionally, the ETM provides a summary of the costs per type of energy. Two examples of the costs per year for a household are shown in Table 7. On the left the average annual costs for a household of using natural gas and no additional insulation in 2016 and in 2045; on the right the costs for an alternative with an air heat pump, green electricity and insulation.

	NATURAL GAS		**AIR HEAT PUMP WITH RENEWABLE ELECTRICTY AND INSULATION**	
	2016	**2045**	**2016**	**2045**
Heat	524 €/year	1190€/year	528 €/year	2020 €/year
Electricity	159 €/year	225 €/year	159 €/year	282 €/year
Fuels	1 €/year	11 €/year	1 €/year	11 €/year
Network	278 €/year	827 €/year	278 €/year	822 €/year
Total	963 €/year	2253 €/year	967 €/year	3135 €/year
	970 €/year	**2300 €/year**	**1000 €/year**	**3100 €/year**

Table 7. The ETM produces a summary of the costs per type of energy, on the left the average annual costs for a household of using natural gas and no additional insulation in 2016 and 2045 and on the right the costs for the air heat pump with green electricity with insulation alternative.

The ETM provides a very precise calculation of the average annual costs per household for each alternative. Such precision could give the wrong impression that there is no uncertainty in these calculations, which are instead subject to a margin of error. To take into account this uncertainty, the values of the costs are rounded up to hundreds, as shown in Table 7. An overview of the rounded-up effects of each alternative on the attribute affordability can be found in Paragraph 9.3 in Table 9.

9.1.3 Availability (2)

The attribute availability is defined as how reliable the energy source for each alternative is. The reliability of each alternative can be determined according to Quintel Intelligence by two variables in the ETM:

- The loss of load hours, i.e. the number of hours when energy needs to be imported to fulfill the demand;
- The blackout hours, i.e. the number of hours when there is not enough energy available to fulfill the demand.

One possibility is to express the attribute availability by showing the number of the loss of load hours and blackout hours. However, it is expected that the average respondent does not understand the meaning of both variables. Therefore, it was decided to use an ordinal instead, where both variables are combined to a reliability scale: Very unreliable (1), Not reliable (2), Neutral (3), Reliable (4), and Very reliable (5).

According to the ETM, only the alternatives with an air heat pump and renewable electricity register blackout hours – 2 per year – which is still an acceptable number. Therefore, these alternatives get the score Neutral (3). All the other alternatives with renewable energy, instead, have some loss of load hours and thus get the score Reliable (4). Lastly, the alternatives with fossil energy do not have any loss of load hours or blackout hours, and consequently get the score Very reliable (5). An overview of the effects of each alternative on the attribute's availability can be found in Paragraph 9.3 in Table 9.

9.1.4 Autarky (3)

Autarky means to be self-sufficient and it is usually applied to political states or their economic systems (English Dictionary, Thesaurus & Grammar Help, 2018). In this case, it is applied to how self-sufficient a country is in producing energy, which can be expressed in import and export numbers. Therefore, the attribute autarky is defined as the share of net energy imports on the total energy demand. In units, this is: % of imported energy. The ETM indicates the import dependency of a country by showing the total amount of net imported energy. The energy imports are divided into the following categories: Coal (1), Oil (2), Gas (3), Uranium (4), Electricity (5), Biomass (6), and Heat (7). In Figure 19, the import dependency of the alternative with an air heat pump and fossil electricity with insulation is shown.

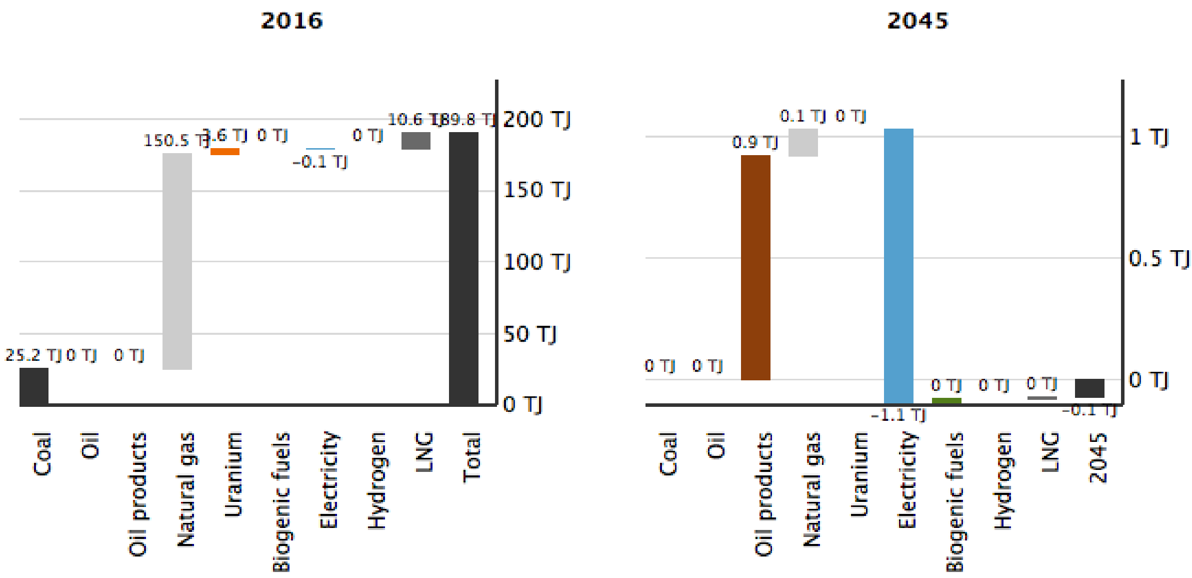

Figure 19. The ETM produces a graph that shows the import dependency of the alternative with an air heat pump and renewable electricity with insulation in 2016 and 2045.

The ETM calculates the percentage as the total net import divided by the primary energy consumption. These calculations are again very precise, yet intrinsically uncertain; to take into account this uncertainty, they are rounded-up to integers. An overview of the effects of each alternative on the attribute autarky can be found in Paragraph 9.3 in Table 9.

9.1.5 Employment (4)

The attribute employment is defined as the growth of employment in the energy sector in comparison to the current level of employment in the same sector. In units, this is: +% of employment. The ETM indicates six fields which can be influenced by the different alternatives used in households: space heating (1), cooling (2), hot water (3), insulation (4), district heating (5) and solar panels (6). Subsequently, for each of these fields a subdivision of five aspects is made: planning (1), production (2), assembly/placement (3), maintenance (4) and removal/replacement (5). Based on this division, Quintel made – in cooperation with Alliander – an estimate of the employment growth.

An example of this subdivision is given in Figure 20, where employment growth between 2016 and 2045 is displayed for the natural gas without insulation alternative. In the x-axis, the FTE unit is used. FTE means Full Time Equivalent: 1000 FTEs are equal to 1800 hours per year.

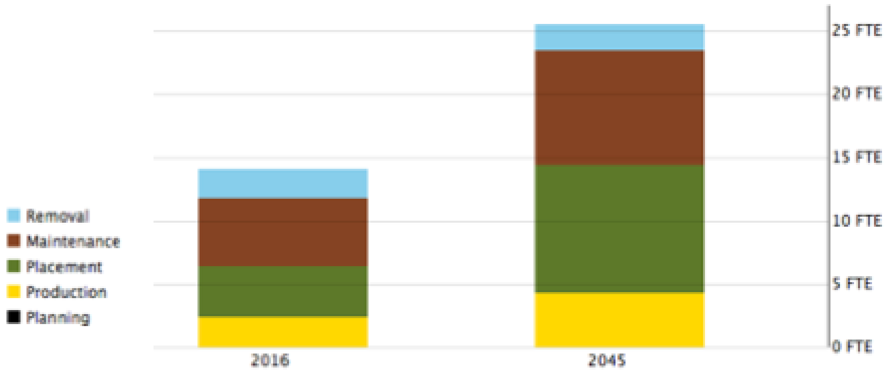

Figure 20. The ETM produces a graph that shows the growth of jobs between 2016 and 2045 for the natural gas without insulation alternative.

The calculation of the employment growth goes as follows: the difference between the FTEs in 2045 and FTEs in 2016, divided by the FTEs in 2016, times 100%. An overview of the effects of each alternative on the attribute employment can be found in Paragraph 9.3 in Table 9.

9.1.6 Ecology (7)

The attribute ecology is defined as the percentage reduction of CO_2 emissions between 2016 and 2045. In units, this is: – % CO_2. The ETM calculates the CO_2 emissions in 2016 and in 2045. These two values are used to calculate the reduction of CO_2 emissions in percentages, of which an example is shown in Table 8.

	2016	2045	DECREASE	REDUCTION
CO_2-EMISSIONS	11.69 kT	1.11 kT	10.58 kT	- 90.5%

Table 8. Example of the calculation of the reduction of CO_2-emissions in percentages between 2016 and 2045

An overview of the effects of each alternative on the attribute ecology can be found in Paragraph 9.3 in Table 9.

9.2 Calculations of attributes based on literature research

As pointed out before, the ETM is not suitable to calculate the effects of each alternative on safety (5), comfortability (6) and nuisance (8). Therefore, the effects of the alternatives on these attributes are estimated through literature research, which will be discussed here.

9.2.1 Safety (5)

The attribute safety is defined as the annual number of national incidents which are caused by the installations of each alternative. In units, this is: # national accidents/year. There are three types of installations: boiler, connection to the district heating network, and air heat pump.

First of all, when a gas boiler is used, carbon monoxide can leak. This led to 40 accidents in 2015 (Netbeheer Nederland, 2015). Second, households which are connected to the district heating network could have leakages of hot water. Annually, a leakage occurs in 3.5% of these households, with 7 leakages leading to accidents where people were burned by the hot water in 2015 (RVO, 2016). Lastly, no information could be found on any accident related to the use of air heat pump in the Netherlands. Considering that an air heat pump works in a similar way as a refrigerator (Milieu Centraal, 2016), it is assumed that no accidents have happened.

An overview of the effects of each alternative on the attribute safety can be found in Paragraph 9.3 in Table 9.

9.2.2 Comfortability (6)

The attribute comfortability is defined as the level of comfort inside the house for each alternative. However, whether a house is seen as comfortable is highly dependent on the preferences of each individual (Klimapedia, 2010). This makes it difficult to quantify the level of comfortability for each of the alternatives. To measure comfortability, an ordinal scale is used: Very uncomfortable (1), Not comfortable (2), Neutral (3), Comfortable (4), and Very comfortable (5). Moreover, it is assumed that whether the heat comes from renewable sources or from fossil sources does not affect the level of comfort. Therefore, only the comfortability level of eight alternatives needs to be estimated.

Overall, there are three aspects that affect the level of comfortability. The first important aspect is the ratio between heat by radiation and convection. Figure 21 shows this ratio for different types of heating installations. Each heating installation conveys both heat by radiation and convection. The ratio is important, because the higher the share of radiation heat, the more comfortable the temperature perceived is. Floor heating has three times the amount of radiation heat in comparison to conventional radiator, which means that using floor heating is more comfortable than conventional radiators (Klimapedia, 2010).

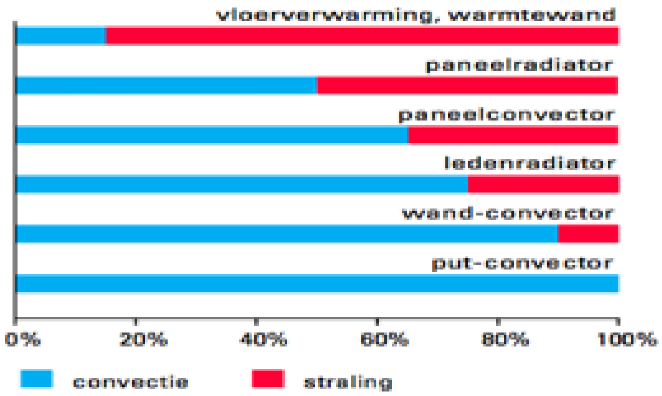

Figure 21. The graph shows the ratio between convection heat and radiation heat for different types of heating. The higher the radiation heat, the more comfortable the space with the heating source is (Klimapedia, 2010).

The second essential characteristic is the relative humidity and quality of the air indoors. Houses with floor heating have relatively less dust, and therefore also less scorched air, due to the fact that there are less dust particles to be burned by radiators. Therefore, in comparison to other options, floor heating provides a higher quality in indoor air (Klimapedia, 2010).

The last characteristic that contributes to the comfortability is the air speed, which is influenced mainly by whether there is a lot of draft in the house. It can be assumed that a poorly-insulated house has more draft than a well-insulated house. The higher the draft, the higher the air speed, which has a negative influence on the comfortability level of the house (Klimapedia, 2010).

These three characteristics can be used to determine the level of comfortability inside the house for each alternative. First of all, the alternatives that have floor heating – air heat pumps and low temperature district heating – without insulation will be very uncomfortable (1). As pointed out before, floor heating provides more radiation that other options, and has a high quality of air. However, for houses without sufficient insulation it is impossible to reach a comfortable temperature of 20° C degrees. Therefore, it will be too cold in the houses to be comfortable.

Second, for the alternatives that have floor heating – air heat pumps and low temperature district heating – with good insulation will very comfortable (5). A sufficient roof insulation, floor insulation, a filled cavity wall and HR ++ glass, in combination with floor heating, make the house very comfortable: high air quality, high percentage of radiation heat, and due to the high level of insulation, no draft. Therefore, these alternatives get the highest comfortability score.

For the alternatives that use gas without insulation a neutral (3) score is given, while for the alternatives that use gas with insulation a comfortable (4) score is given. The majority of the houses in Hengstdal uses a central heating boiler, for which only conventional radiators are required. It is assumed that the majority of the households have these conventional radiators (*ledenradiatoren)*, which are less comfortable than floor. Additionally, most houses in Hengstdal have an energy label of E, which means that they do not have sufficient insulation. Nevertheless, it is assumed that the level of comfort inside the majority of houses in Hengstdal is at least Neutral (3). Besides, the alternatives with insulation are more comfortable than the average house in Hengstdal, which means that they score higher and are comfortable (4).

Lastly, for alternatives that are connected to the high temperature district heating network, both conventional radiators and floor heating are suitable. Moreover, no insulation is required to reach comfortable temperatures in the house, due to the high temperature of the water that is used to heat. In order to address the fact that these alternatives have two possibilities for heating, a less precise score is given to both. The alternative with insulation scores either Comfortable (4) with conventional radiators, or Very comfortable (5) with floor heating. The alternative without insulation scores either Neutral (3) with conventional radiators, or Comfortable (4) with floor heating – both one score lower due to the draft caused by the lack of insulation.

An overview of the effects on the attribute comfortability of each alternative can be found in Paragraph 9.3 in Table 9.

9.2.3 Nuisance (8)

In the study of Motivaction, respondents pointed out that it is important that the nuisance for local residents must be limited. Therefore, the attribute nuisance is defined as the possibility to have noise disturbance for local residents. The attribute is categorized according to the following ordinal scale: No noise disturbance (1), possible noise disturbance (2). Overall, only the alternatives with air heat pumps have the possibility of noise disturbance: at peak load, the noise of an air heat pump could reach up to 60 dB, which is similar to the noise produced by an air-conditioning unit (Vakblad Warmtepompen, 2017). For the other alternatives, no noise disturbance is reported. An overview of the effects of each alternative on the attribute nuisance can be found in Paragraph 9.3 in Table 9.

9.3 An overview of all the effects of each alternative on the constraint and attribute

In the previous paragraphs, through the ETM and literature research, all the effects on the constraint and attributes of each alternative are calculated. An overview of the effects of each alternative on the attribute and constraint can be found in Table 9.

6. Calculate effects on contraint and attributes

An overview of the effects of each alternative on the constraint and attributes is provided in Table 9, which is step 6 of the PVE method. The table show the 16 alternatives on the most left column and the attributes and their according units on the first row.

Now that all the effects on the constraint and attributes of each alternative are calculated, the next step is to compose the rest of the content of the web tool of the PVE method. This will be discussed in the next chapter.

	Alternatives/Attributes	Renewable energy sources [%]	Affordability [€/year/ household]	Availability [1-5]	Autarky [% export]	Employment [+% jobs]	Safety [#incidents/ year]	Comfort [1-5]	Ecology [% reduction CO_2-emissions]	Possibility of noise [yes/no]	Energy use in 2045 compared to 2016 [%]
Gas	Natural gas without insulation	9	2300	5	92	160	40	3	-28	1	95
	Green gas without insulation	95	2800	4	70	285	40	3	-69	1	95
	Natural gas with insulation	15	1900	5	84	91	40	4	-69	1	48
	Green gas with insulation	100	2600	4	68	152	40	4	-89	1	48
Electricity	All-electric with gray electricity without insulation	19	3200	4	88	340	0	1	-39	2	45
	All-electric with green electricity without insulation	84	3400	3	1	599	0	1	-78	2	55
	All-electric with gray electricity with insulation	36	3100	5	77	190	0	5	-80	2	22
	All-electric with green electricity with insulation	81	3100	3	1	256	0	5	-88	2	24

	Alternatives/Attributes	Renewable energy sources [%]	Affordability [€/year/ household]	Availability [1-5]	Autarky [% export]	Employment [+% jobs]	Safety [#incidents/ year]	Comfort [1-5]	Ecology [% reduction CO_2-emissions]	Nuisance [#days]	Annual energy use (TJ)
Low Temperature heat	L.T. heating with gray heat source without insulation	9	3700	5	93	107	9	1	-12	1	87
	L.T. heating with green heat source without insulation	66	3200	4	56	229	66	1	-42	1	87
	L.T. heating with gray heat source with insulation	17	2800	5	87	37	17	5	-61	1	44
	L.T. heating with green heat source with insulation	69	2900	4	62	96	69	5	-54	1	42
High Temperature heat	H. T. heating with gray heat source without insulation	9	3800	5	93	107	7	3,50	-12	1	93
	H. T. heating with green heat source without insulation	65	3300	4	56	231	7	3,50	-42	1	93
	H. T. heating with gray heat source with insulation	16	2800	5	87	37	7	4,50	-61	1	46
	H. T. heating with green heat source with insulation	68	3000	4	62	97	7	4,50	-45	1	44

Table 9. Overview of the effects of each alternative on the constraint and attribute

10 THE CONTENT OF THE WEB TOOL FOR THE HENGSTDAL CASE STUDY

The main objective of this chapter is to provide a clear overview of the web tool which is used for the implementation of the PVE method in this case study. The web tool gathers information about the preferences of the residents of the case study neighborhood, which means that it needs to be understandable in order to provide a clear overview of the effects of each alternative to the residents and should meet the expectations and constraints set by the municipality.

The TAA web tool will be used as a base for the web tool developed for this case study. In Chapter 5, the following distinction between the content of the web pages was made:

1. Content of the introduction and instruction pages – step 7 of the PVE method
2. Content of the information pages – step 8 of the PVE method
3. Content of the delegation page – step 9 of the PVE method

Paragraph 10.1 will discuss the composition of the content of each page briefly. Moreover, based on the survey of VEH – which shows that 40% of the homeowners do not understand the matter of energy transition well enough – it is assumed that a significant part of the residents of Hengstdal would not fully understand the implications of the transition of Hengstdal to zero natural gas use. Therefore, in order to make the web tool clearer, several elements are added to the main page, which will be discussed in Paragraph 10.2. These elements have been approved by the creator of the PVE method. The process of making the web tool clearer has been an iterative process that started already at the beginning of January. During this process, several different concepts have been considered. An overview of the most important concepts of this iterative process are given in Appendix D.

10.1 The content of the web tool

The TAA web tool was used for as a base for developing the web tool in this case study. However, the content of the TAA web tool must be replaced with content specifically composed for this case study.

The content of the web tool must meet the three conditions that were introduced in Chapter 5. In order to check whether these conditions were met, the creator of the method was consulted several times. After several iterations, a satisfactory solution was found. The composition of the content of each page will be discussed briefly here. A complete overview of the content of the web tool can be found in Appendix C.

7. Compose introduction and instruction pages

The pages provide information about the purpose of the web tool and what is expected from the respondents. It explains in what context the experiment takes place and under what constraint. It also provides a video that shows how to navigate the web tool. An extra information page is added in order to make clear that the alternatives are built out of three choices. Another information page is added – as requested by the municipality – to explain how the attribute *affordability* was calculated.

8. Compose information pages

Each information page is based on the research conducted in Chapters 6-9. The information pages provide basic information about the choices related to each alternative and highlight the effects of the alternative on the most relevant attributes.

9. Compose delegation page

The delegation page provides the respondents with the opportunity to delegate their decision to an expert or to the other residents of the neighborhood. However, they must choose this option without knowing what the results of the delegation will be. In this way, the residents can provide a clear indication on whether they want – or not – to have the responsibility of deciding over the transition towards zero natural gas use.

10.2 The main page of the web tool

The main page of the web tool[7] is shown in Figure 22. In order to make the web tool clearer, the main page of the TAA web tool was used as a basis and several elements were added. The main page of the TAA web tool can be found in Figure 31 in Appendix A.

The following ideas were incorporated in the main page in order to make the design clearer:

1. A bar which shows whether the goal to achieve 100% renewable energy sources is met.
2. A table to show the effects on the attributes of the selected alternative. The units of measure were also added to the table. In this way people can understand better what each number means.

[7] The web tool, specifically designed for the Hengstdal case study, is available on the following website: http://nijmegen.participatie-begroting.nl/

3. A pie chart to show the total energy consumption of the neighborhood and the impact of adding insulation. Due to the fact that respondents could only choose one alternative at the time, it was not useful to keep the pie chart at the prominent place it had in the preparatory concepts. Therefore, it was moved next to the bar. In this way, people can still see what the effects are of selecting an alternative on the energy consumption.
4. A clear green mark for the alternatives that have renewable energy sources – as a compromise to the more expensive suggestion discussed above.
5. The title that shows which alternative is selected. It also shows in text how much energy is consumed and what percentage of the renewable energy constraint is met. This is added because it could help people understand the pie chart and bar better.

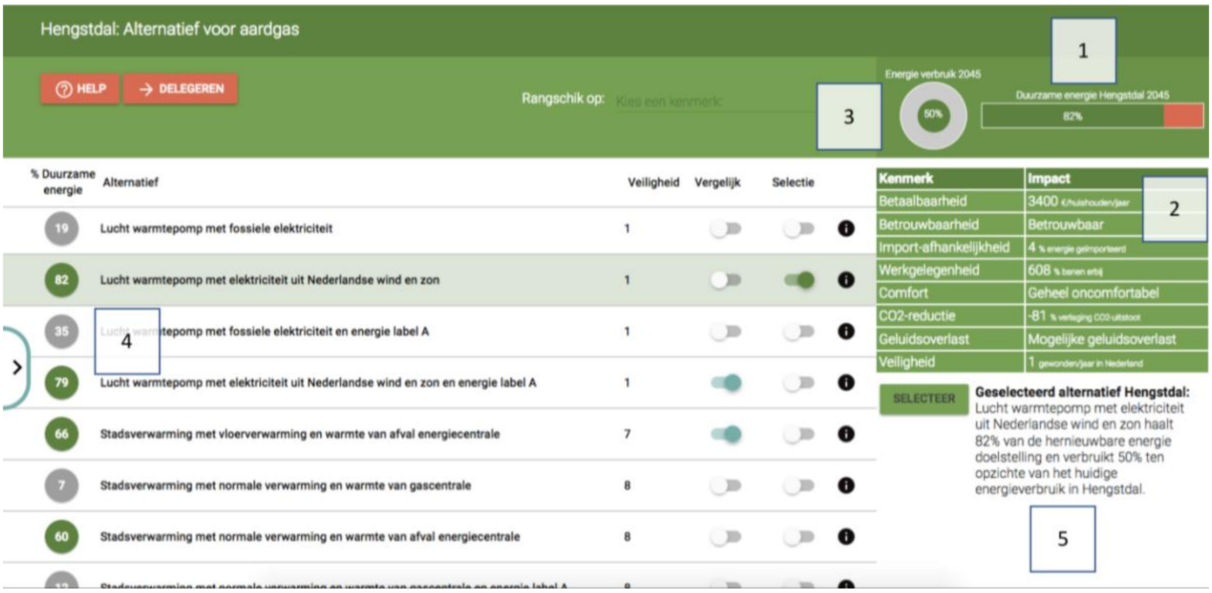

Figure 22. A print screen of the main page of the final design of the web tool for the Hengstdal case study.

It must be pointed out that, in choosing the content of the web tool, there is a trade-off between the goal to provide a complete overview of all the available alternatives, making it as realistic as possible and making it as understandable as possible. The final design and content is considered to be balanced. Now that the design and development of the web tool for the Hengstdal case study are explained, the next step is to implement the web tool. This will be discussed in the next chapter.

11 IMPLEMENTATION AND RESULTS OF THE CASE STUDY

The purpose of this chapter is to provide a clear analysis of the results of the research conducted in this thesis. This is important, because in order to analyze the results, the web tool first needs to be implemented. This will be discussed in Paragraph 11.1. The results are presented in Paragraph 0. In Paragraph 11.3, the process of conducting the research in this thesis is analyzed. From this analysis, factors that complicated the process are identified. In order to avoid future applications of the PVE method to suffer from the same complicating factors, a list of conditions will be formulated. However, future research is required in order to determine whether these conditions – if met – will be sufficient.

11.1 The implementation of the web tool

It was agreed with the municipality of Nijmegen, one of the main stakeholders, that they would be responsible for the implementation of the web tool. The municipality would spread the web tool amongst the residents of Hengstdal in their name, since they financed the development of the web tool.

On June 15th, the municipality was informed that the web tool was ready to be spread amongst the residents of Hengstdal. Eleven days later, on June 26th, a news item about the web tool – with the link to the web tool – was placed on the neighborhood website by Duurzaam Hengstdal.[8] This was not in line with what was discussed earlier on. To explain what happened, first a brief overview of the events between June 15th and June 26th is given:

Jun 15th *The municipality is informed that the web tool is ready to be spread amongst the residents of Hengstdal*

Jun 20th *The municipality says that the web tool looks great except one point: the calculation of the costs shown in the attribute affordability require a better explanation.*

The municipality agrees that placing an extra information page about the calculation of the affordability prior to the main page would be sufficient. The web tool will be spread amongst the residents after the weekend of the 25th.

Jun 22th *The municipality states that Duurzaam Hengstdal should be contacted for spreading the web tool, because the tool is focused on Hengstdal and not on the municipality of Nijmegen. And Duurzaam Hengstdal has a mailing list of 250 involved residents of Hengstdal at its disposal.*

[8] The neighborhood website with the article about the web tool is available on the following website: https://nijmegen-oost.nl/bericht/welk-alternatief-kiest-u-voor-aardgas-maak-uw-keuze-via-deze-webtool

Jun 25th *Mr. Van der Wiel, of Duurzaam Hengstdal, indicates that he feels under pressure now that he is suddenly made responsible for spreading the web tool. He consults other members of Duurzaam Hengstdal and states that they are not willing to spread the web tool.*

Mr. Van der Wiel explains that in June a meeting was held with representatives of the residents of Hengstdal, where it was decided to exclude the options of keeping natural gas or switching to biogas. These options are included in the web tool (options of doing nothing and switching to biogas), so Mr. Van der Wiel states that this would give residents the impression that those options are still available.

Jun 26th *As a compromise, it is suggested to accompany the web tool with some explanatory notes on how the residents have to interpret the web tool. In summary, the note explains that the purpose of this tool is not to replace the policy making of the municipality and of Duurzaam Hengstdal, but to gain insight into the considerations underlying a choice, and that it is still a test. Additionally, the note explains that the web tool includes alternatives which are no longer up-to-date for a district like Hengstdal, but that the residents still have the opportunity to select them and explain why they prefer this alternative anyways.*

The changes were made and the web tool was placed on the neighborhood website by Duurzaam Hengstdal. The website sends weekly updates to its subscribers. Duurzaam Hengstdal was not willing to use the mailing list of 250 involved residents.

Two weeks later, 0 residents of Hengstdal filled in the web tool. In order to convince people to fill in the tool, it was decided to go into the neighborhood on July the 10th and ask people directly.

Jul 10th *Spreading flyers in Hengstdal and ringing doors for at least 2.5 hours, in order to make people aware of the web tool and personally ask them to fill in the web tool. At least 30 people were spoken to and indicated that they would fill in the tool.*

Jul 12th *6 residents of Hengstdal have filled in the web tool.*

11.2 The results of the web tool

In the end, **6 residents of Hengstdal have filled in the web tool.** The number of responses is not sufficient for an in-depth analysis of the preferences of the residents of Hengstdal. However, a short description will be given about the quantitative and qualitative data that was gathered by the web tool on these 6 responses in order to show the future possibilities of the PVE method.

Of the 6 respondents, only 2 people filled in the web tool after the afternoon of July 12th. It must be concluded that only 2 people were convinced by directly asking them to actually fill in the tool – out of at least 30 people which were enthusiastic about the web tool and had indicated that they would fill in the web tool. Additionally, another 50 flyers – the other 30 were given to the people that were spoken to – were spread in the neighborhood.

11.2.1 The preferred alternatives

From the data gathered by the web tool, shown in Figure 23, it can be concluded that first of all none of the respondents chose the alternative “do nothing”, which means that they are all willing to change their current situation. However, there is no consensus among the 6 respondents on a preferred replacement of natural gas: Two respondents prefer the alternative “High Temperature District heating with heating from the Waste Power plant ARN with insulation”, two respondents chose an air heat pump and fossil electricity (only one with insulation) and two opted for biogas (only one with insulation).

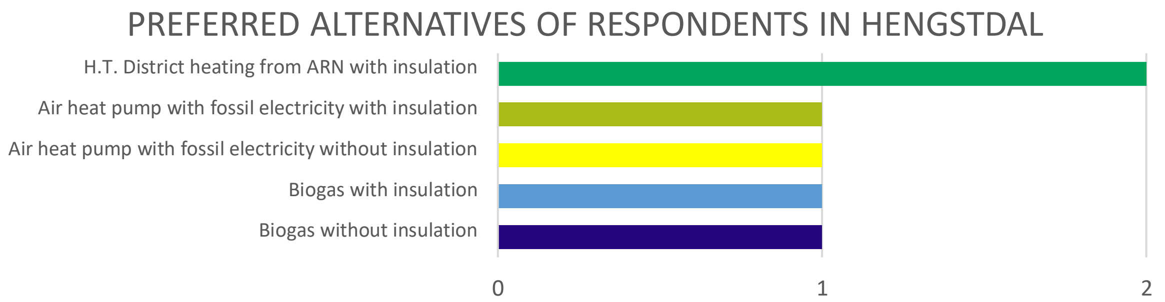

Figure 23. Preferred alternative of each respondent in Hengstdal.

Figure 24 shows where each respondent lives in Hengstdal and displays their preferred alternative. The map also shows which houses are owned by the housing corporations. All the responses come from houses which are not owned by the housing corporations. An explanation for this could be that only private home-owners felt the need to fill in the web tool, since they can choose which alternatives they prefer for their houses. While the dwellers of houses owned by the housing corporations do not have any influence on the alternative installed in their houses.

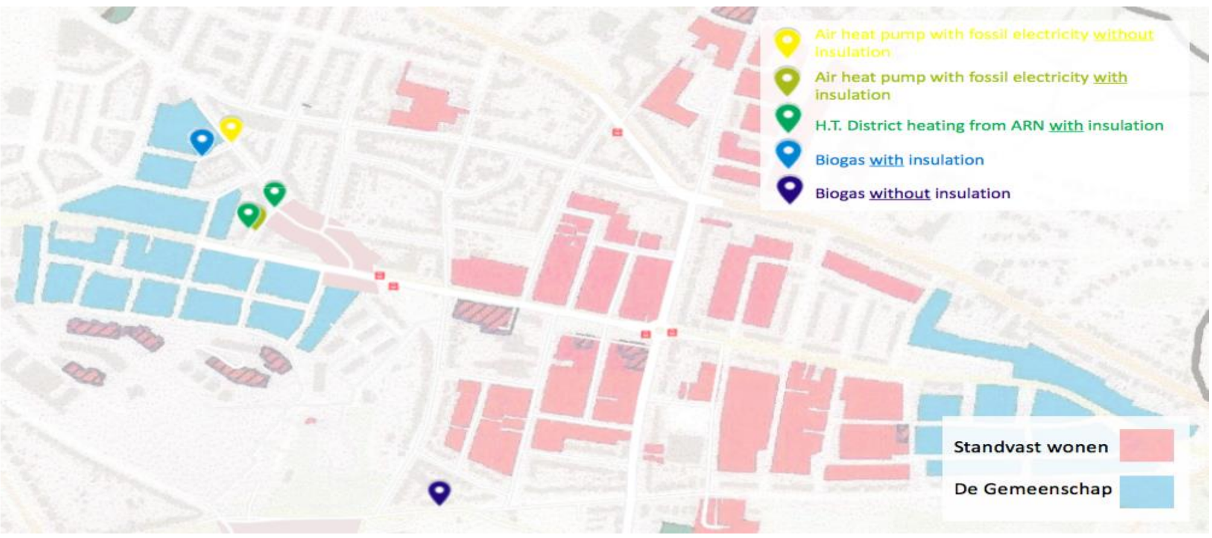

Figure 24. Distribution of the alternatives in Hengstdal.

Figure 25 shows an overview of the decisions made on the three choices each alternative is composed of. Out 6 respondents, 4 chose the option to insulate their house, and 4 opted for renewable energy. However, only 3 out of 6 chose to have both insulation and renewable energy.

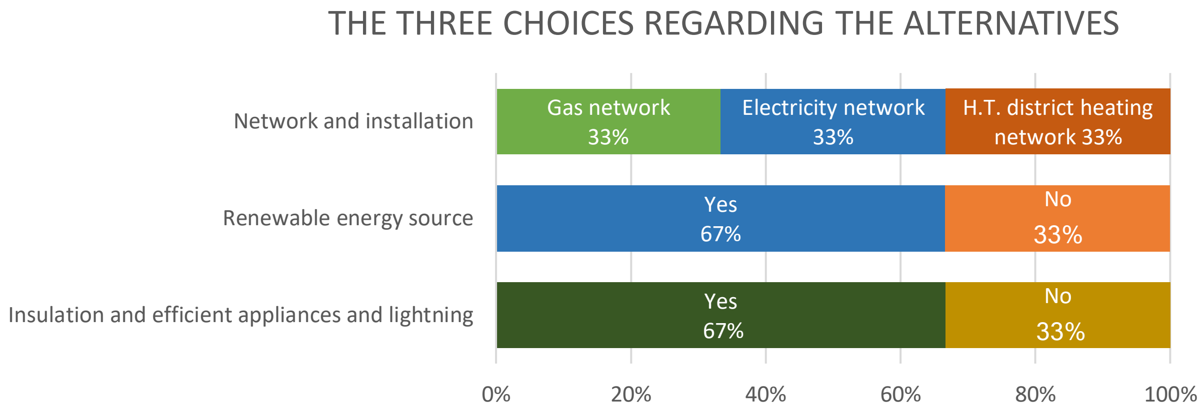

Figure 25. The three choices the respondent can make regarding the alternatives, which are the choices between: different types of networks and insulations, renewable and fossil energy sources, and insulation, efficient appliances and lightning or not.

Some of the respondents also motivated their choices. One of the two respondents that chose high temperature district heating said that floor heating is not an option for him or her, because the respondent has an old house and thus low temperature district heating – which requires floor heating – would not be possible. The other respondent indicated that waste would be a good energy source, because it will never run out.

Two respondents chose the alternative with an air heat pump with fossil electricity. The first respondent chose the alternative without any insulation. This means that the respondent either did not see the score of the comfortability – which is uncomfortable – or that the respondent does not value comfortability. The other respondent said that the alternative with an air heat pump on fossil electricity with insulation is a reasonable solution.

Lastly, there are two respondents that chose the alternative with biogas – only one with insulation. The respondent that chose biogas without insulation explains that it is the option with the least alterations to the current infrastructure in the house and neighborhood, while it is still a renewable alternative. However, no conclusions can be drawn from the motivations, due to the low number of respondents.

11.2.2 Relevant background data on the respondents

Based on the answers on the background questions, a description of the current energy system of the six respondents is given. All respondents have an individual boiler and – except one with energy label E – nobody knows the energy label of their house. Moreover, one respondent has solar panels.

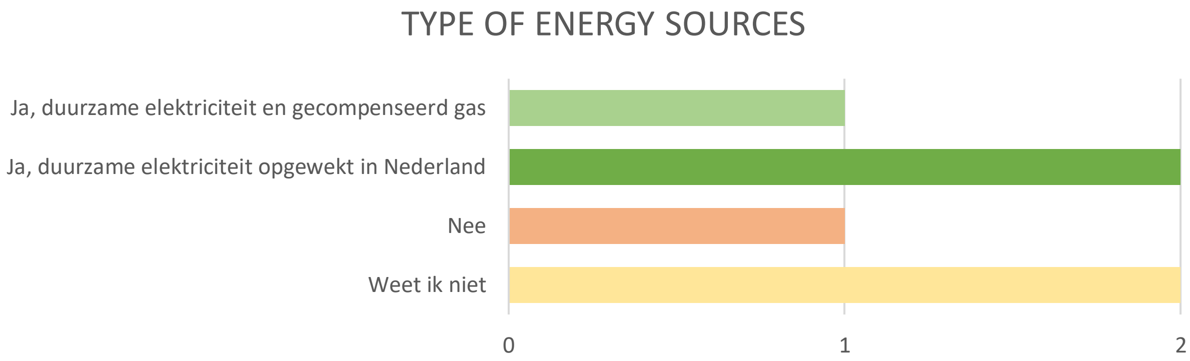

Figure 26. The type of energy sources which are used by each respondent.

Overall, respondents which already had renewable energy before also chose an alternative with renewable energy for the future. However, one respondent that currently has renewable electricity chose the alternative with an air heat pump and fossil electricity. Two things could be concluded from this: the respondent no longer wants renewable electricity, or the respondent might have thought that — because he or she already had renewable electricity — it was no longer necessary to also select this in the web tool.

Moreover, there is only one respondent that indicates that he/she is planning to move in the next 5 years. This respondent chose an alternative with an air heat pump – an unexpected result, since this is one of the alternatives that require the greater investment.

Due to the low number of respondents, it is not possible to draw any conclusions between the preferred alternatives and the answers given to the follow-up questions about the background.

11.2.3 Evaluation experiment

The respondents were also asked several questions in order to value the experiment. Figure 27 shows the results. First, they indicated that they were all convinced of the alternative that they chose. Second, most respondents indicated that they believe it is a realistic experiment – only one feels neutral about it. All respondents appreciate the effort of the municipality to develop an experiment like this. However, half of the respondents are not convinced that this will provide the municipality with relevant information.

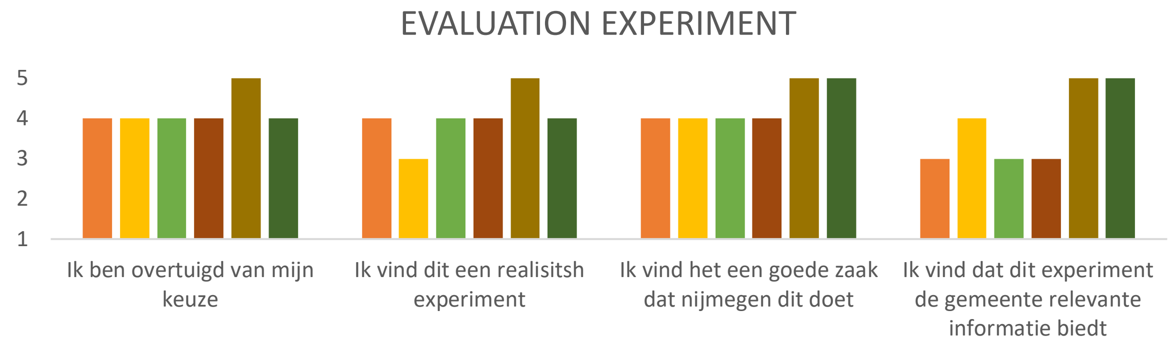

Figure 27. The results of each question about the evaluation of the experiment.

No general conclusions can be made about the evaluation of the PVE method, however, it can be concluded that the six respondents were predominantly positive about the web tool.

11.3 Analysis of the process

The next step is to analyze the application process of the PVE method in the research of this thesis. From this analysis, factors that complicated the process are identified. In the course of this thesis, several deliverables – in collaboration with different parties – were produced. For the purpose of analyzing the complete process, all collaboration processes were incorporated in one comprehensive timeline, which is shown in Table 10.

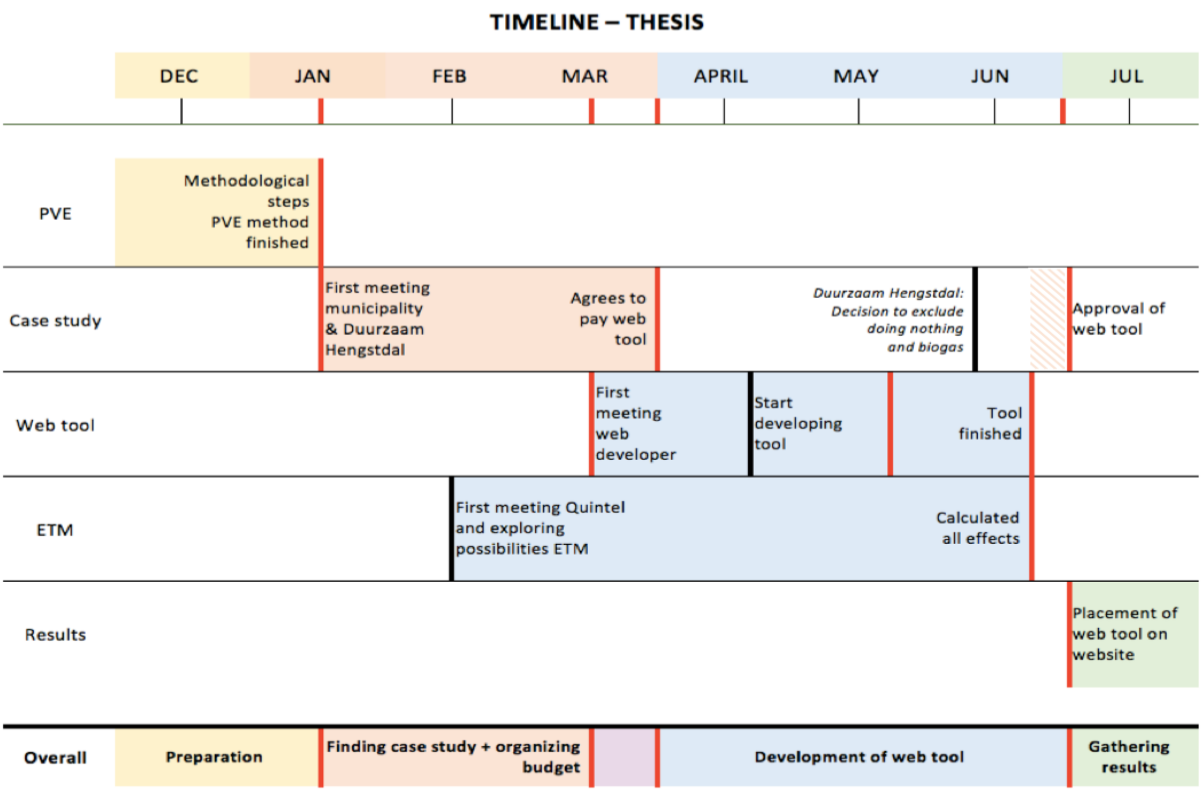

Table 10. All collaboration processes incorporated in one comprehensive timeline.

From the timeline, it can be seen that the first month and a half were used for preparation, finding the case study and organizing the budget. Two and a half months were spent on developing the web tool. Only two weeks were left for the implementation of the method, of which one week was lost due to problems with approving the web tool. It can be concluded that developing and implementing the PVE method required a significant amount of time. Moreover, the participatory element of the method requires a high degree of coordination among the various stakeholders involved, which adds to the complexity of the process.

Seven factors are identified that complicated the process of conducting the research in this thesis. Each factor will be discussed separately:

1. A **high number of steps has a finish-to-start dependency**: one step needs to be finished in order to start the next step (Nicholas &and Steyn 2012). In Table 10, these finish-to-start dependencies are showed by the red vertical lines. The most important steps are listed here:

Deduction of the methodological steps of the PVE method	→	*Convincing the **municipality and Duurzaam Hengstdal** to participate in the case study*
*The **municipality** agrees to pay for the web tool development*	→	***Web developer** starts working on the web tool*
*Exploration of all possibilities and limitations of the ETM together with **Quintel Intelligence***	→	*Calculation with the ETM of the effects of the alternatives on the constraint and the attributes*
*The web tool is finished by the **Web Developer***	→	*Approval of the web tool by the **municipality and Duurzaam Hengstdal***
*Placement of web tool by **Duurzaam Hengstdal***	→	*Gathering the results and analyzing the preferences of Hengstdal*

   The problem is that if a delay occurs in one of the finish-to-start dependency steps, it will also lengthen the critical path of the whole project. Two of these steps – the agreement of the municipality to pay for the web tool development and the development of the web tool – were delayed by a month, which also led to the delay of the research conducted in this thesis.

2. The majority of the **critical steps could only be finished in collaboration with other stakeholders**. The collaboration with Quintel Intelligence was without any problems. However, the collaboration with the municipality and the web developer was more difficult:
   a. The municipality had to undergo lengthy internal procedures to take a final decision about the financing of the web tool development. The whole procedure lasted longer than one month.

   b. The web developer was only able to start developing the web tool a month after the decision of the municipality, due to personal circumstances. This highlights the degree of complexity in coordinating the work of all the relevant stakeholders.

   These circumstances alone resulted in a two-month delay of the research planned.

3. The responsibility of the municipality and Duurzaam Hengstdal towards the case study changed several times during the course of this thesis:
   - At the start of the project, the municipality indicated that Duurzaam Hengstdal would be responsible;
   - Later on, the municipality took back the responsibility and decided to finance the web tool development, demanding that their sponsorship be clearly stated in the web tool. When this development was finalized, the municipality approved the web tool;
   - At the moment of spreading the tool, the municipality shifted the responsibility back to Duurzaam Hengstdal, which no longer felt responsible for the project and thus rejected to spread the tool via email. This caused further delays in the spreading of the web tool, which eventually was not disseminated as proposed but just posted online.

   It can be concluded that there was **no agreement on the project owner**: the shared responsibility of both stakeholders resulted in no clear responsibility of any of them.
4. The involved parties had **no significant financial commitment**, because the research was conducted for a Master's thesis and no financial reimbursement for the researcher was expected. Only the municipality paid the web developer 3000 euros, a small fraction of the total budget of the municipality. Neither the municipality nor any other party involved would suffer any financial damage if the case study failed. Therefore, none of the parties involved felt responsible for successfully completing the research conducted in this thesis.
5. The transition of Hengstdal had already started before the beginning of the thesis and was continued during the implementation of the research project. In June, it was decided to exclude the options of keeping natural gas or switching to biogas, which meant that **the content of the web tool was no longer in accordance with reality**. However, the documentation of each step in the process, from preparation to development of the web tool, is a time-consuming process – even without any delays. Due to the planning of the thesis, there was no time left to make the required adjustments.
6. The decision-making process in Hengstdal has evolved rapidly and the final decision on an alternative for natural gas must be made before the end of 2018. Before taking the final decision, the web tool can be used to explore the preferences of the residents of Hengstdal regarding the transition of the neighborhood towards zero natural gas use. The results of the web tool would assist the municipality and Duurzaam Hengstdal in the decision-making process without removing

their mandate. Following the decision of Duurzaam Hengstdal to exclude some alternatives, only the alternatives for an electrical heat pump and district heating were still seen as desirable. If the results of web tool showed that a large share of the residents of Hengstdal prefer biogas – an undesirable alternative according to the municipality and Duurzaam Hengstdal – it would significantly hurt the mandate of the municipality and Duurzaam Hengstdal to make the final decision. **If the main stakeholders already have a desirable solution, the added value of the tool will become increasingly smaller in the eyes of those stakeholders.**

7. **At the local level of the neighborhood the TNS NIPO database cannot be used in order to reach and motivate people to participate in the PVE method**. From the 30 people which all indicated to fill in the web tool, only 2 actually filled in the web tool. In the previous case studies, the TNS NIPO database was be used to select a representative sample and motivate them by paying the respondents, which is not possible because the local level of a neighborhood limits the possibilities for finding a representative sample in a national database as TNS NIPO. Additionally, there was no budget available to motivate the participants to participate in the PVE method by offering them a financial reward.

The analysis identified seven factors which complicated the process of conducting the research in this thesis – from the design of the PVE method to implementation of the PVE method. In order to avoid future applications of the PVE method to suffer from the same complicating factors, a list of conditions will be formulated. However, future research is necessary in order to determine whether these conditions – if met – will be sufficient to avoid the process – of the application of the PVE method to the transition towards zero natural gas use at the local level of an existing neighborhood to suffer from these complicated factors – to suffer from these complicated factors. Table 11 shows the seven conditions which were formulated as an answer to the 7 complicated factors which were identified in this research:

COMPLICATING FACTORS	**CONDITIONS**
1. High number of steps has a finish-to-start dependency 2. Critical steps can only be finished in collaboration with other stakeholders	1. All stakeholders are aware of *what* their critical tasks are in the process of conducting the research. 2. All stakeholders are aware of *when* these critical tasks need to be finished.
3. No agreement on the project owner 4. No significant financial commitment	3. There is only one project owner, who feels responsible for the successful implementation of the method due to a significant *financial commitment*.
5. The content of the web tool was no longer in accordance with reality	4. All stakeholders have to agree on a timeline for the decision-making process and it must be agreed in advance that the results of the PVE method will used as an input for this decision-making process

	5. Resources must be sufficient to finish the research within the available timeframe.
6. The main stakeholders already have a desirable solution.	6. The decision-making process is in the initial phase of exploring possible alternatives, which means that pronouncements have been made about any preferred alternatives.
7. At the local level of the neighborhood the TNS NIPO database cannot be used in order to reach and motivate people to participate in the PVE method.	7. In the application of the PVE method, sufficient time must be spent on the design of a communication strategy in order to reach and motivate enough residents of the neighborhood – with or without financial rewards.

Table 11. The conditions on the right are formulated in an attempt to avoid future research to suffer from the complicating factors on the left.

Now that the analysis of the process is finished, the complicated factors are identified and a list of conditions that could avoid future applications of the PVE method to suffer from the same complicating factors is put together, the next step is to answer the main research question. This will the done in the next chapter.

12 CONCLUSION

In this thesis, the focus lied on investigating the possibilities of the application of a novel method for the assessment of the transition towards natural gas-free neighborhoods in the Netherlands: the Participatory Value Evaluation method. The main objective of this thesis was to contribute to the development of the PVE method by researching its applicability to the transition towards zero natural gas use at the local level of an existing neighborhood. The following knowledge gaps were addressed:

- There is no methodological paper available on the design of the PVE method and the content of the related web tool.
- It is the first application of the PVE method on the topic of the transition towards zero natural gas use.
- It is the first application of the PVE method at the local level of a neighborhood.

In order to address these knowledge gaps, the PVE method was applied to a case study on the transition towards zero natural gas of the neighborhood Hengstdal in Nijmegen. By applying the PVE method on the case study, the main research question in this thesis could be explored: to what extent is it possible to apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood. In order to apply the PVE method to the case study, it was first necessary to determine the methodological steps of the PVE method (SQ1). Then, after the application of the PVE method to the case study (SQ2-SQ6), the implementation process was evaluated (SQ7). These seven sub questions were answered by the research conducted in this thesis.

First, in order to answer SQ1, it was necessary to determine what methodological steps were needed to apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood. There was no methodological paper on the PVE method available. Therefore, existing sources from two prior case studies were used to deduce the steps for the PVE method. 5 methodological steps on the design of the PVE method were deduced: choose the context, set the constraint, design the follow-up questions, determine the alternatives and select the attributes. 4 methodological steps on the composition of the content of the web tool: calculate the effects of the alternatives on the constraint and the attributes, compose the content for the introduction and instruction pages of the web tool, compose the content of the information pages and compose the content of the delegation page.

In order to answer SQ2, it was necessary to provide an overview of the context in which the Participatory Value Evaluation method is applied. The neighborhood that was selected for this case study is Hengstdal in Nijmegen. The context of the PVE method (step 1) in this case study was as follows. The municipality of Nijmegen aims at becoming energy neutral in 2045. The first step of this transition is to transform the neighborhood Hengstdal into a natural gas-free neighborhood by 2045. There are several alternatives for natural gas and the municipality of Nijmegen wanted to consult the residents of Hengstdal to investigate which alternative they preferred. Consequently, the constraint of the case study (step 2 of the PVE method) is for Hengstdal to become energy-neutral by 2045, which is measured as the share of renewable energy sources used by households in Hengstdal in 2045.

The stakeholder analysis showed that the municipality and Duurzaam Hengstdal were key stakeholders in regard to the application of the PVE method. However, private homeowners possess the most power, because the PVE method can only be applied if they decide to participate in the experiment. Moreover, 56% of the houses in Hengstdal are owned by housing corporations. The housing corporations indicated that they were not interested to participate in the PVE method. Moreover, the local energy system of Hengstdal currently provides only the opportunity for the installation of solar panels, which can serve as part of an alternative to natural gas if heat pumps are also installed. However, in the broader area of the municipality of Nijmegen, the waste incinerator with the district heating network and a possible new wind turbine provide prospects for future alternatives for natural gas.

Lastly, five relevant background variables were identified that could be of influence on the preferences of the citizens on each alternative: (1) the type of energy contract, (2) the type of installation, the level of insulation as described by (3) the building year of the house and (4) the energy label of the house, and (5) the type of cooker. These relevant background variables were used to design the follow-up questions (step 3 of the PVE method).

Moreover, in order to answer SQ3, it was necessary to decided what alternatives to natural gas were available for the case study neighborhood (step 4 of the PVE method). Sixteen possible alternatives were selected in total, with each alternative being a combination of the following three choices: (1) the choice of a fossil or a renewable energy source, (2) the choice about installing insulation or not, and (3) the choice among four different types of networks (gas, electricity, high temperature heating, low temperature heating) with their relative installations (respectively high efficiency boiler, air heat pump, normal radiators or floor heating).

Then, in order to answer SQ4, the attributes regarding the transition towards zero natural gas use were selected (step 5 of the PVE method). The attributes were selected from a study on the most important values regarding the energy transition conducted by Motivaction in 2017. These values were used as input for the selection of the following attributes: affordability, availability, autarky, comfort, nuisance, ecology, safety and employment impact.

Thereafter, in order to answer SQ5, the effects of each alternative on the attributes and constraint were calculated (step 6 of the PVE method). The Energy Transition Model provided the opportunity to design energy scenarios in order to calculate the effects of each alternative. An overview of all the effects can be found in Table 9.

In order to answer SQ6, a clear overview of the web tool used for the implementation of the PVE method in this case study was provided. The TAA web tool was used for as a basis for developing the web tool needed for this case study, but the content of the web tool had to be replaced (step 7, 8 and 9 of the PVE method). A detailed overview of the content of the web tool can be found in Appendix C. In order to make the web tool more understandable, several elements were added to the main page and were approved by the creator of the PVE method.

Lastly, in order to answer SQ7, the factors that complicated the application of the PVE method at the local level to the transition of a neighborhood to zero natural gas use were identified. Only 6 respondents filled in the web tool, and therefore the focus of the analysis lied mainly on identifying the complicating factors in the design and implementation of the PVE method. The complicating factors that were identified are: the high number of steps which have a finish-to-start dependency, the necessary reliance on other stakeholders to complete some critical steps, the lack of a clear project owner with a significant financial commitment at stake, the content of the web tool that – at a later stage – was no longer in accordance with reality because some of the main stakeholders had already decided that some alternatives were more desirable, and the impossibility to use the TNS NIPO database at the local level of the neighborhood in order to reach and motivate people to participate in the experiment.

Due to the fact that only 6 respondents filled in the web tool, it must be concluded that it was not possible to successfully apply the Participatory Value Evaluation method to the transition of the case study neighborhood towards zero natural gas use. Moreover, it must be concluded that the PVE method is very time-consuming to implement. At the same time, collaboration with several stakeholders is needed to conduct the PVE method. Every stakeholder needs to be closely involved in the implementation of the PVE method and, in particular, in the development of the web tool. The researcher needs to be aware of the fact that involving citizens in the decision-making process implies creating boundaries for the ability of policymakers to choose independently the alternative that they believe is most desirable. Consequently, policymakers – the municipality and Duurzaam Hengstdal in this case – demanded to be closely involved in the process in order to monitor whether the research was going to meet their expectations. Because of this involvement – especially of the main stakeholders of the case study – the content and scope of research could change rapidly. This is hard to combine with the more rigid character of academic research, where every step needs to be substantiated and documented.

To avoid future applications of the PVE method to suffer from the same complicating factors, the following conditions were formulated: to successfully apply the PVE method to a case study on the transition towards zero natural gas use at the local level of an existing neighborhood, there should be only one project owner, who feels responsible for the successful implementation of the method due to a significant financial commitment. All the stakeholders involved in the PVE method should be aware of both what their critical tasks in the process of conducting the research are, and of the deadlines by which these critical tasks need to be finished. Moreover, when the case study is applied at the local level, sufficient time should be spent on the design of a communication strategy in order to *reach* and *motivate* enough residents of the neighborhood to participate in the experiment – with or without financial rewards. For case studies at the regional or national level, the TNS NIPO database could instead be used to reach a higher number of respondents, but sufficient financial resources should be allocated for this purpose.

Lastly, the PVE method should be applied on a decision-making process that is still in the initial phase of exploring possible alternatives, which means that no pronouncements about any preferred alternative have been made yet. All stakeholders have to agree on a timeline for the decision-making process and it must be agreed in advance that the results of the PVE method will be used as an input for the decision-making process. Resources – both in terms of money and researchers – must be sufficient to finish the research within the available timeframe.

If these conditions are met, they could avoid or mitigate the impact of the complicating factors and could therefore make it possible to successfully apply the Participatory Value Evaluation method to the transition towards zero natural gas use at the local level of an existing neighborhood. However, further research is necessary in order to determine whether these conditions are sufficient, as will be discussed in the last Chapter of this thesis.

13 DISCUSSION

This chapter will discuss the results of the research conducted. The discussion will be articulated around five topics:

- The possibilities and limitations of the PVE method;
- The specificities of the Hengstdal case study;
- The complicating factors in carrying out the research,
- The new applications of the ETM and its limitations,
- Suggestions for future research.

13.1 The possibilities and limitations of the PVE method

A first problem of the method is that the results of the PVE must be incorporated in the local decision-making process. The PVE method provides a way to citizens to express their preferences, which can be used as an input for the decision-making process of policymakers. However, it must be considered that policymakers have their own policy preferences as well. Therefore, implementing the PVE method has two key implications for policymakers– such as the municipality of Nijmegen or Duurzaam Hengstdal in this thesis. On the one hand, if the preferences expressed by the citizens coincide with those of the policymakers, the PVE method provides a sound mandate to the policymakers for implementing their preferences. On the other hand, if the preferences of the citizens and those of the policymakers do not coincide, the PVE method could limit the ability of policymakers to pursue their own preferences. Thus, the PVE method entails both opportunities and threats for policymakers, as became clear during the research carried out for this thesis. At the beginning of the project, both the municipality of Nijmegen and Duurzaam Hengstdal showed keen interest in implementing the PVE method for the Hengstdal case study. However, as the research became better defined, also the risks of gathering information about the citizens' preferences through the web tool became clearer for both key stakeholders and resulted in the limited coverage of the web tool. For example, Duurzaam Hengstdal indicated that some viable alternatives in the web tool were no longer in line with their policy preferences and therefore they did not want to promote the web tool any more in order to avoid the risk of residents choosing those options.

Second, applying the PVE method to a real-world case study is time-consuming and potentially costly, if the involved decision-makers (e.g. the local or national government) have to hire qualified researches for this task. Therefore, decision-makers that want to use the PVE method to assess a certain problem must be willing and able to provide a budget for the research. Yet, a highly successful implementation of the PVE method is not necessarily desirable for policy-makers. This could potentially lead to a higher demand for PVE assessments in the future – either from public opinion or from political (opposition) parties. A large-scale use of PVE assessments, however, could escalate the costs of implementing the method, while reducing the room for discretion for policy-makers, as explained above.

A third limitation of the PVE method is that the related web tool must be made available online and is in the current design accessible to everybody. This could lead to problems of self-selection of the sample and, consequently, falsification of the results. For example, in the Hengstdal case study, residents of other neighborhoods could potentially fill in the web tool, or some Hengstdal's residents could fill in the tool multiple times. Therefore, even though the goal of the PVE is to facilitate citizens' participation, some restrictions to access the web tool might be necessary to avoid falsification of the results.

Fourth, it is not possible to assess whether the web tool is understandable or not for the respondents. Answers given by the respondents could be based on a faulty understanding of the web tool. For example, one of the respondents to this research indicated the wish to switch back to natural gas heating, instead of the renewable energy source he/she currently has, violating the constraint of the research (becoming a gas-free neighborhood by 2045). This answer might be based on a wrong understanding of the functioning of the web tool.

13.2 Discussion about the specificities of case study

The first specific complication of the case study conducted in this research is the complexity of the topic. The transition towards natural gas-free neighborhoods is highly complex because of the numerous variables involved and their interactions, e.g. district heating that becomes cheaper the more users are connected to it, biogas that is only limitedly available, or the insulation level that can significantly impact the values of the attributes of a house. It is a significant challenge to clearly communicate these complex interactions to citizens in a simple and understandable way. The web tool was a compromise in this regard, but further research has to be conducted in order to determine whether it was a sufficient compromise. It could be possible that the topic of the transition towards natural gas-free neighborhood is too complex to involve the public in the decision-making process.

A second important consideration about this specific case study is that, differently than the previous applications of the PVE method, it mainly involves the use of private money – not public money. Most of the alternatives would be financed by private money, i.e. homeowners can choose their preferred alternative but have to invest their own money to implement it. Some homeowners indicated that they simply do not have the funds to invest in any alternatives – the question is, it is possible to motivate those citizens? The municipality (or the government) could only partially contribute by establishing subsidies. The previous case studies, instead, clearly regarded the allocation of public investment. The lack of clarity about who is going to bear the costs of the transition to natural gas-free neighborhoods complicates the research and its clear communication to the citizens further.

A third specificity of the case study is the involvement of Duurzaam Hengstdal. The neighborhood's initiative consists of only a small group of involved residents who speak on behalf of the whole neighborhood. The position of Duurzaam Hengstdal, however, is strongly influenced by the personal preferences of its representatives. This became clear when those representatives pointed out that some of the alternatives from the web tool were labeled as 'not desirable'. The involvement of Duurzaam Hengstdal, therefore, added a further layer of complexity to the implementation of the PVE method and complicated the opportunity to involve *all* residents directly in the experiment.

A last consideration is again related to the specific topic of the case study. The energy transition is currently on top of the government's agenda and many relevant policies at both national and local level are being negotiated, e.g. the negotiations on the Climate Law, the closure of the coal-fired plants, the halt to the extraction of natural gas in Groningen, or the geopolitical implications of being dependent on energy imports from Russia or Norway. The context in which the transition of the built environment towards zero natural gas use takes place is therefore changing fast and is unpredictably: this makes the forecasts about the effects of each alternative unreliable, affecting the whole experiment.

13.3 Discussion about the complicating factors in carrying out the research

One of the problems with the Hengstdal case study was the fact that the decision-making process on the transition of the neighborhood continued while the research was ongoing. Duurzaam Hengstdal decided that it was no longer desirable to choose the alternatives that involved biogas or natural gas. However, the communication about the decision-making was not sufficient, because both parties were busy with their own part of the transition. In order to conduct the PVE method, the researcher needs to be very proactive in approaching and keeping all the stakeholders involved. However, this is something challenging because of the time-consuming nature of the PVE method.

Moreover, it is important that every stakeholder is fully aware of its role in the process and dedicates enough efforts to the successful implementation of the method. This did not fully happen in the research conducted for this case study. For example, the web developer delayed the production of the web tool, causing a mismatch with the planned timeline. This proved to be relevant since, in the meantime, Duurzaam Hengstdal took the decision to disregard some of the possible alternatives. As a result, the final web tool did not meet the expectations of Duurzaam Hengstdal anymore and a time-consuming negotiation to reach a compromise had to be conducted.

13.4 Limitations of the ETM

The ETM model was used to calculate the effects of each alternative on the attributes and constraint. This was an innovative use of the model which, however, also had several limitations. First of all, one of the main features of the ETM is to be easily accessible online and aimed at reaching as many users as possible. To keep the model simple and easy to use, Quintel Intelligence decided to connect the variables in the model only through linear relations. However, in reality there are many feedback loops that could cause the values of the variables to change exponentially instead of linearly.
Another function that is not included in the ETM is the possibility to conduct sensitivity analyses. This is necessary in order to establish how robust a scenario and the underlying assumptions for each variable are.

Another problem is the scope of the ETM. It has 300 variables, and the definition of some of these variables is not always clear. To clarify how some variables are defined, a close collaboration with Quintel Intelligence was necessary. A researcher could thus encounter several problems while using the ETM if he or she does not have the opportunity to closely collaborate with the developers of the model.

Lastly, even the 300 variables of the model are not enough to provide a complete picture of reality. For example, it is not possible to include floor heating as an option in ETM simulations. In this research, a lower heating consumption was used as a proxy for floor heating. This solution, however, does not take into account the cost of installing floor heating. It should also be noted that this research failed to incorporate the difference between low and high temperature heating in terms of the amount of accidents they cause, which is relevant for the attribute *safety*, since this is not included as a variable in the ETM.

13.5 Suggestions for future research

Based on the research conducted in this thesis, several suggestions for future research can be provided.

First of all, the collaboration with the municipality and Duurzaam Hengstdal should be continued in order to fine-tune the implementation of the PVE method in Hengstdal. An effective communication strategy should be prepared in order to make the residents of Hengstdal aware of the experiment. An option for reaching a higher number of respondents could be to comply with the requests of Duurzaam Hengstdal and omit the alternatives that include natural gas or biogas from the web tool. This could be sufficient to gain the full support of the neighborhood's initiative in further spreading the tool. A high number of respondents would then allow to analyze the preferences of the residents and offer a significant input to local policy-makers for their energy policy decisions.

Moreover, the municipality of Nijmegen indicated that they are interested in applying the PVE method to two other neighborhoods in Nijmegen: Bottendaal and Zwanenveld. These cases could be interesting for further research because discussions about their transition to zero natural gas use are still in the exploratory phase. This implies that policy-makers might be more willing to cooperate with the research since the moment of the

Future research is also necessary in order to determine whether the conditions highlighted in this thesis will be sufficient for a successful implementation of the PVE method. Future case studies must only have one project owner who feels responsible for the successful implementation of the method due to a significant financial commitment. All the stakeholders involved in the PVE method must be aware of both their critical tasks in the process of conducting the research and of the deadlines by which those critical tasks need to be finished.

Furthermore, when the case study is applied at the local level, sufficient time must be spent on the design of an effective communication strategy in order to *reach* and *motivate* enough residents of the neighborhood to participate in the experiment – with or without financial rewards. For case studies on the regional or national level, instead, the TNS NIPO database can be used to reach the respondents, but sufficient financial resources must be allocated for this purpose.

Ideally, the PVE method should be applied on a decision-making process that is still in the initial phase of exploring possible alternatives, which means that pronouncements about any preferred alternative have not been made yet. All stakeholders have to agree on a timeline for the decision-making process and it is important to agree in advance that the results of the PVE method will used as an input for this decision-making process. Resources – both in terms of money and researchers – must be sufficient to finish the research within the available timeframe.

In order to test whether the above-mentioned conditions are sufficient, the research in this thesis should be repeated on similar case studies. However, as indicated, the research conducted in this thesis was both on a new topic and at a new level. Further research should be conducted on case studies that differ in at least one of these aspects to test the set of conditions highlighted in this thesis. For example, studies on the same topic – the transition towards zero natural gas use – but at a different level – regional or national – should be conducted.

Additionally, as mentioned above in the discussion, a solution must be found for the fact that web tool is available online and is accessible to everybody without a limit on the times it is filled in. This means that residents could manipulate results and that residents from outside the neighborhood could also use the web tool.

Lastly, due to the fact that there were only 6 responses to this experiment, the options for providing suggestions for future research on analyzing the results gathered through the web tool are limited. However, one main possibility is discussed here because its applicability seems promising. The maps provided by Google Maps can be used to analyze the data gathered: it is possible to provide an overview of the alternatives sorted by location, as shown in Figure 28, by entering the postal codes in a personal map.

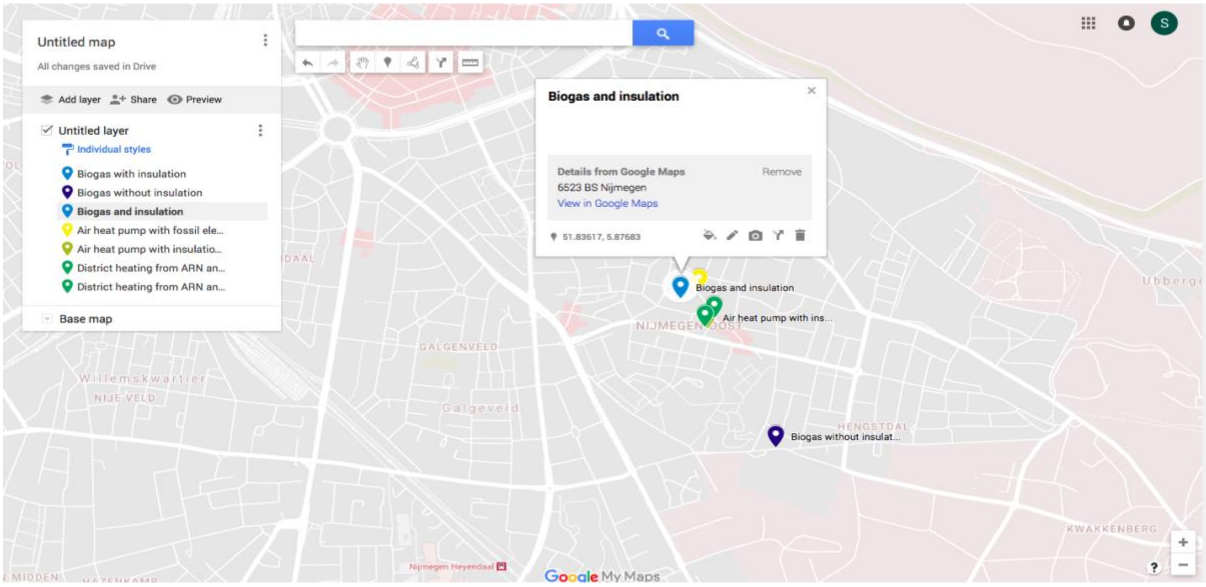

Figure 28. Print screen of google maps to construct a map.

The possibilities for creating maps like this are numerous. First, the different preferences for alternatives can be color-coded and added in different layers: this makes it possible to easily switch between different types of alternatives. Second, as was done in Figure 24, the maps created by Google Maps can be placed on top of other existing maps of the neighborhood. This can be used to compare the distribution of different alternatives to, for example, annual income, energy consumption, type of house etc. Another interesting option is the fact that the map can be uploaded and made accessible to everybody. In this way, the residents of Hengstdal could be informed about how the distribution of the preferences for the alternatives to natural gas are spread amongst their own street or in their whole neighborhood.

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15 APPENDIX

In the appendix overviews are presented that includes information which is too detailed for the main body of the paper.

Appendix A – Deduction of methodological steps based on web tool

In this appendix, the deduction of the composition of the content of the web tool are discussed. In order to understand what content is required by web tool, the TAA case study web tool[9], developed for the TAA case study to evaluate the preferences of the citizens on the TAA's transport policy decisions, is analyzed.

Figure 29. A print screen of the introduction page of the TAA web tool.

The first page that respondents see when opening the link is the introduction page, which is shown in Figure 29. The page introduces the experiment and provides information about the context of the research: which party needs advice on what topic under what timeframe.

[9] There is demo version available on the following website: http://www.participatie-begroting.nl

Figure 30. A print screen of the instruction page of the TAA web tool.

On the second page, further explanation is provided about the context of the research. Also, instructions are given on how to use the web tool. Figure 30 shows the print screen of the instruction page. First, a text is provided with instructions, where it is clearly stated what is expected from the respondents. Then, to make sure that the respondents really know how to navigate the web tool, there is the opportunity to watch a short instruction video where everything is explained. After finishing the video, the respondent is ready to go to the main page. Thus, based on the context, decided upon in step 1, the introduction and instruction page for the web tool are generated **(step 6)**.

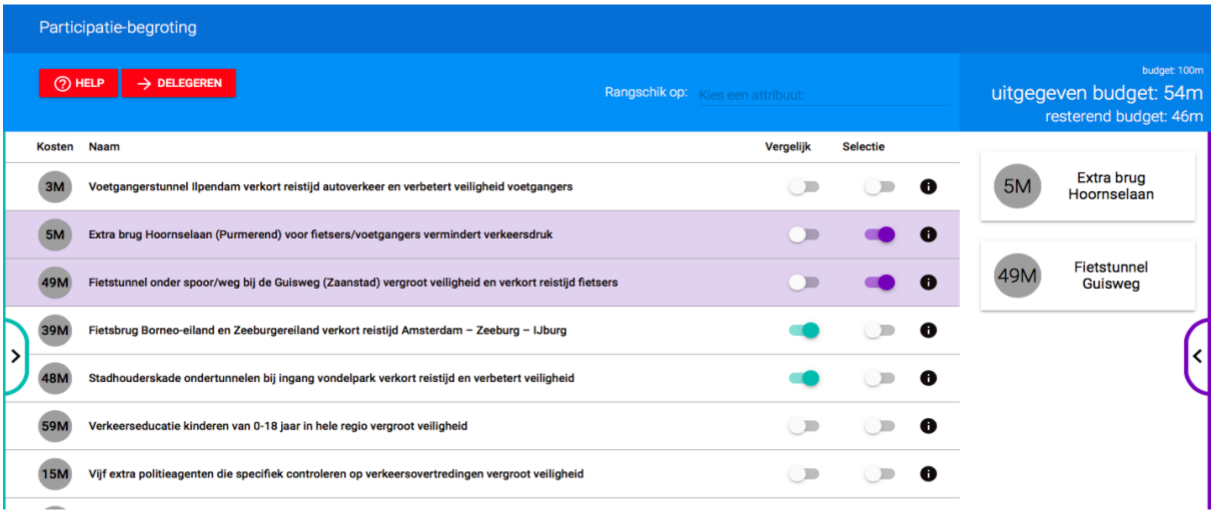


Figure 31. A print screen of the overview page of the TAA web tool. Here the projects can be compared and selected. Additional information can be obtained by clicking on the black information button.

At the main page, the projects are presented in a list, as shown in Figure 31. Projects can be compared by using the green comparison button next to the name of the project. They can also a project with purple selection button next to the name of the project. On the right upper corner, it is shown whether the set of selected projects is still within the budget constraint. Also, information is provided about the projects and the attributes. Thus, the next step **(step 7)** is to gather information on the constraint (chosen in step 2), the projects (determined in step 3), and the attributes (selected in step 4).

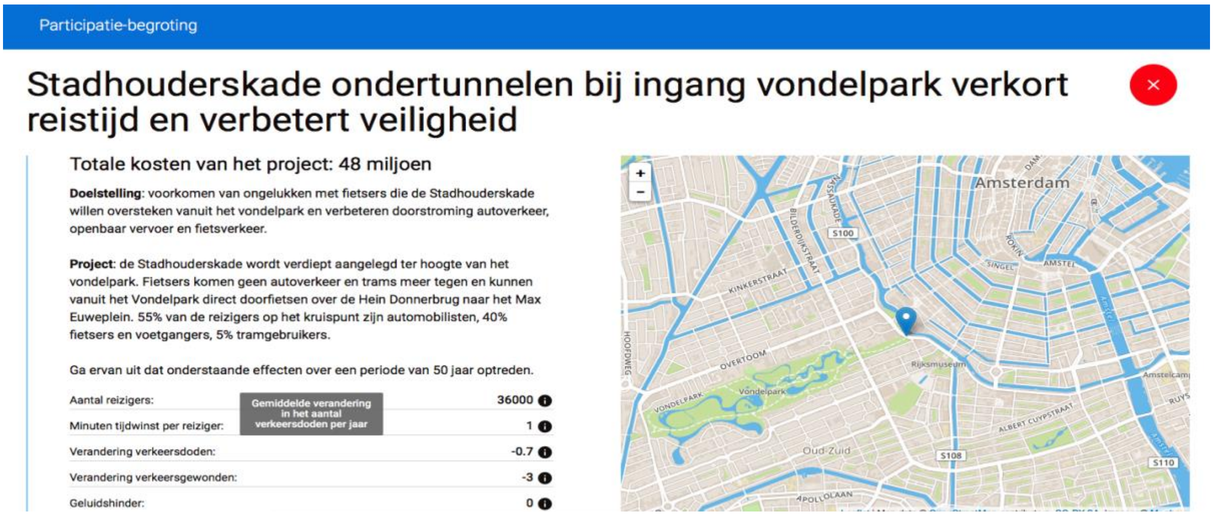


Figure 32. A print screen of an information page of the TAA web tool. Here more information is provided about the goal of the project, the attributes and the location of the project.

By clicking on the black information button next to the project, the respondent will be redirected to the information page, which is shown in Figure 32. Here, the respondent can find more detailed information about the project.

Figure 33. A print screen of the comparison page of the TAA web tool. Here projects can be compared.

By clicking on the green comparison button with the black arrow on the left side of the screen, the respondent will be redirected to the comparison page. Figure 33 shows a print screen of this page. Here, an overview is provided of the **effects** on the constraint and attributes of each selected project.

It also provides the opportunity to sort them on each attribute. In order to show these effects, research and calculations must be conducted **(step 8).** Then, back at the main page, by clicking on the purple selection button with the black arrow on the right side of the screen, the respondent will be redirected to the selection page.

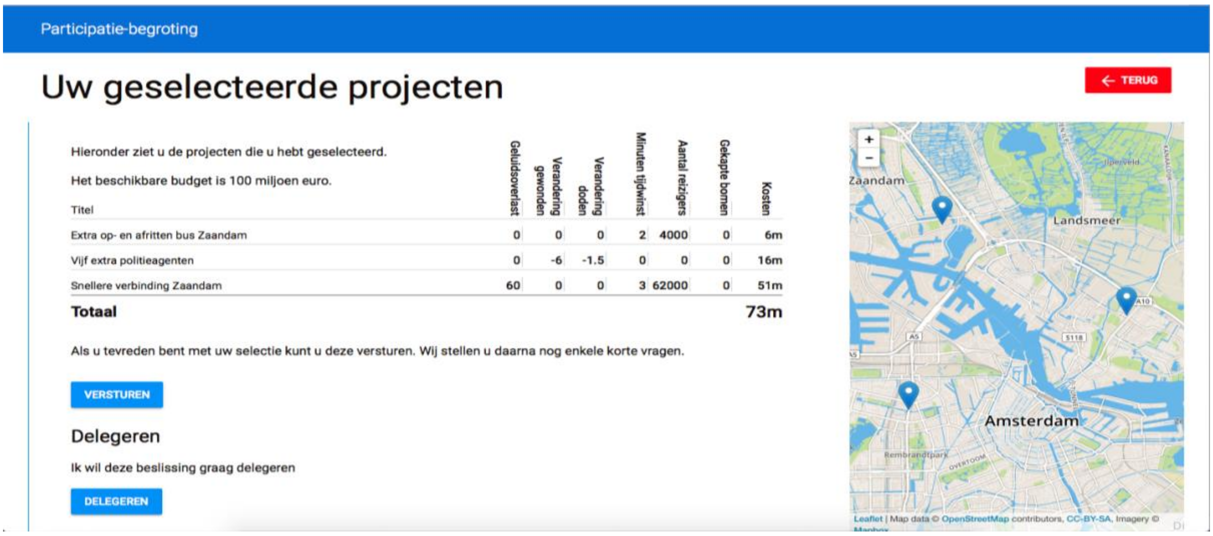


Figure 34. A print screen of the selection page of the TAA web tool. Here an overview of the selected projects is given.

Here, respondents will see an overview of their selected set of projects, Figure 34 shows a print screen of this page. The last choice the respondents have to make is to either select its own preferred set or to delegate the decision to one of the experts.

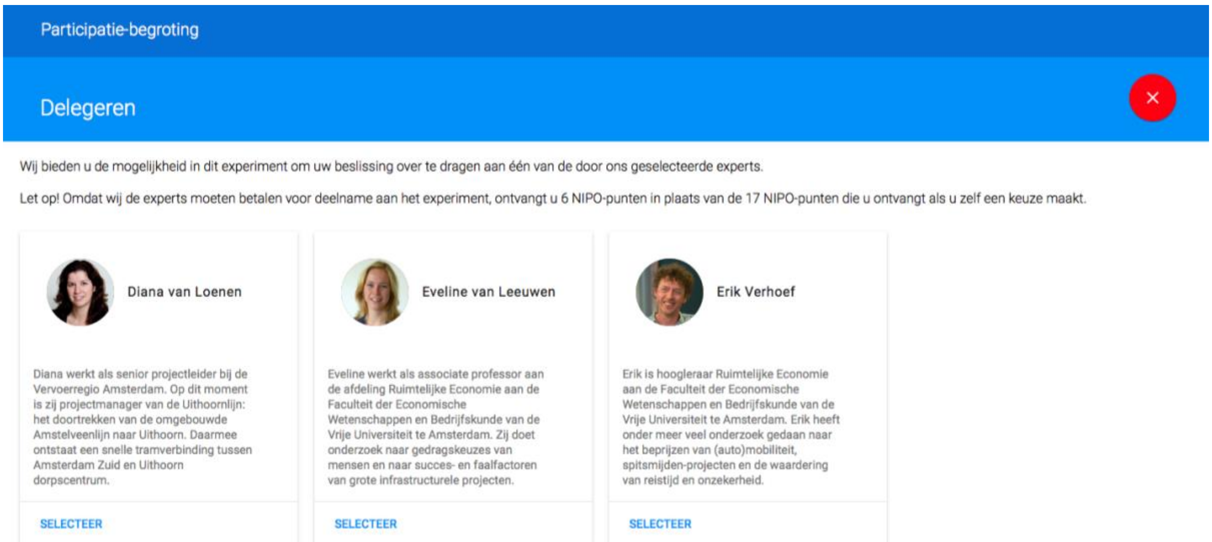


Figure 35. A print screen of the delegation page of the TAA web tool. Here an overview of the selected projects by different experts is given.

When a respondent chooses to delegate its choice, he or she is redirected to the delegation page. On this page, of which a print screen is shown in Figure 35, several experts are introduced. The respondent can dedice that he wants to delegate his choice to one of these experts without knowing what the expert will advice. The last step is **select the experts (step 9).**

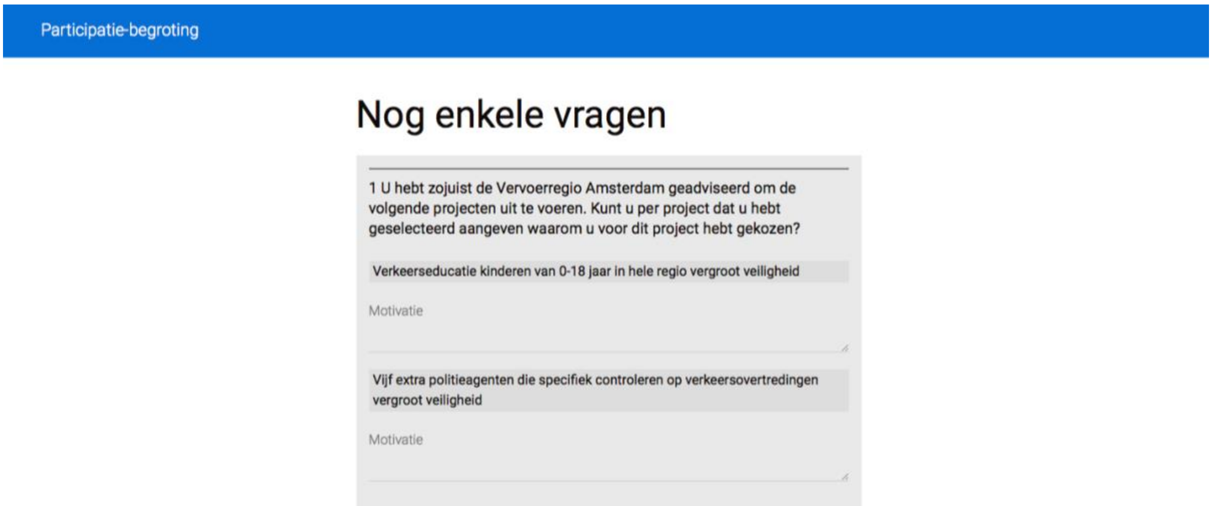


Figure 36. A print screen of the follow-up questions page of the TAA web tool. Here several follow-up questions are asked to gather qualitative data that could be used to interpret that the results on the preferences.

The final step of the web tool are some concluding follow-up questions. Respondents are not only asked to further explain their choices, but also to indicate how realistic they think the experiment is, and last they have to answer some background questions. Figure 36 shows a print screen of the first question. These follow-up questions are already designed in step 5 of the PVE-method, which means that the page does not require any additional step.

Appendix B – Detailed comparison between Hengstdal and the Netherlands

In this Appendix, a detailed comparison between Hengstdal and the Netherlands is provided. The data discussed in this chapter, was used as input for the energy scenarios of the ETM.

Hengstdal has 3,845 households with an average size of 1.7 family members, which is low compared to the Dutch average of 2.17 family members (CBS, 2018C; CBS, 2016c). The neighborhood has 7,010 residents, consisting of 3,335 men and 3,675 women, which results in a population density of 8,343 residents/ km^2 (CBS, 2016c). Additionally, 33% of the population in Hengstdal is between 45 and 65 years old, which is a higher share than the national average (CBS, 2016c). With 59%, the majority is unmarried (CBS, 2016c). The distribution of gender and age for both Hengstdal and the Netherlands are shown in Figure 37 (CBS, 2018C; CBS, 2018D; CBS, 2016c).

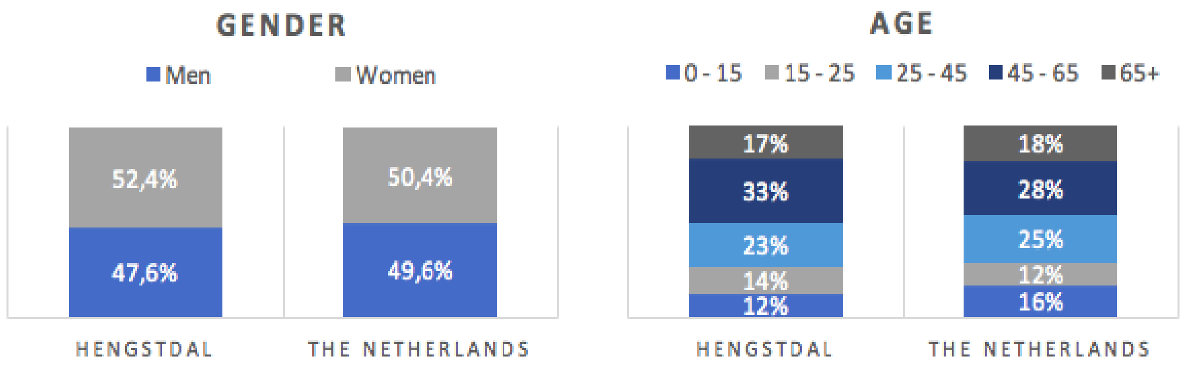


Figure 37. The distribution of gender (l) and age (r) of Hengstdal and the Netherlands (CBS, 2018C; CBS, 2018D; CBS, 2016c).

In addition, 10% of the population is divorced (CBS, 2016c). Only 22% of families in the area has children (CBS, 2016c). Most of the population – 54% of households – is composed of single-person households (CBS, 2016c). These percentages and the Dutch distribution (CBS, 2018C) are displayed in Figure 38. In comparison with the Dutch average, there are more unmarried residents and more single-person households in (Hengstdal CBS, 2018C; CBS, 2016c).

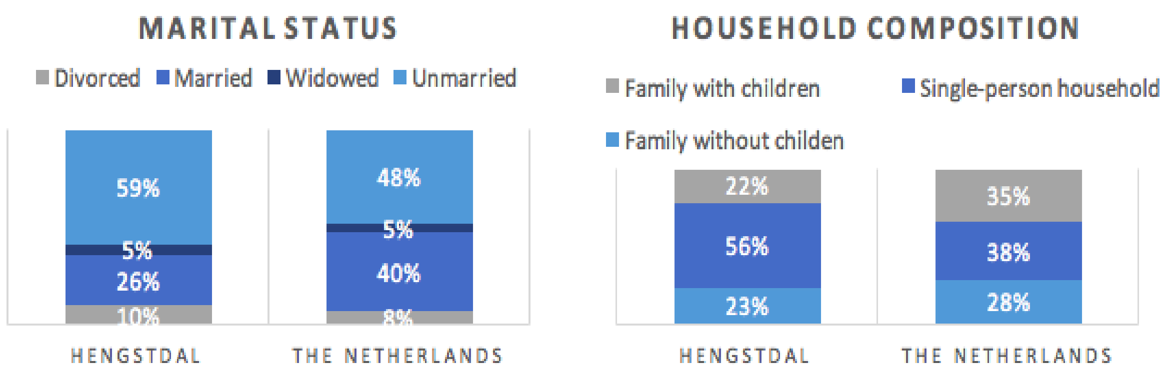


Figure 38. The distribution of marital status (l) and household composition (r) of Hengstdal and the Netherlands (Hengstdal CBS, 2018C; CBS, 2016c).

The origin of the residents in Hengstdal is shown in Figure 39. The majority of the residents, 76%, is of Dutch origin (CBS, 2016c). Then, there is 1% Moroccans and 1% Antilleans, 2% Turkish and the rest are either migrants from Western countries – 12% – migrants from Non-western countries 7% (CBS, 2016c). This is comparable to the level of diversity in the country (CBS, 2018C; CBS, 2016c).

Figure 39 also shows the results of the latest national elections for the Second Chamber for the seven political parties with the most votes. The VVD won the elections in the Netherlands (Kiesraad, 2017), however in Hengstdal *GroenLinks* received the most votes (NOS, 2018). Additionally, there is a large difference between the scores of the *PvdD* and the *CDA* in Hengstdal and the Netherlands (Kiesraad, 2017; NOS, 2018). The *PvdD* got 9% of the votes in Hengstdal, while less than 1% nationally – while the *CDA* got less than 1% of the votes in Hengstdal – 12% nationally (Kiesraad, 2017; NOS, 2018). It can be concluded that Hengstdal favors the left political parties more than the average Dutch voter (Kiesraad, 2017; NOS, 2018).

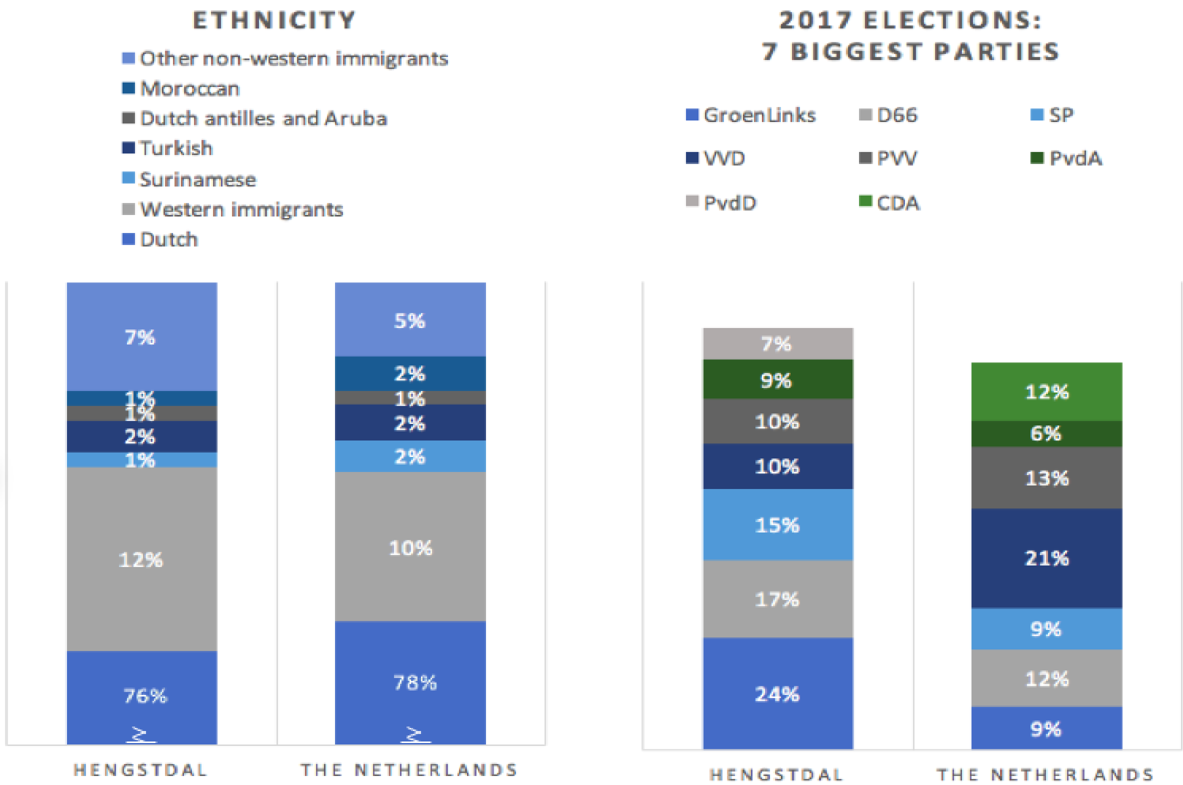


Figure 39. Distribution of ethnicity (l) (Hengstdal CBS, 2018C; CBS, 2016c) and the 7 biggest political parties of Second Chamber elections of Hengstdal and the Netherlands(r) (Kiesraad, 2017; NOS, 2018).

The average income of a resident in this neighborhood is 23,000 euros a year, and 43% of the neighborhood has a low income, in comparison to a national average of 11,5%. (CBS, 2014; CBS, 2018F). Additionally, in Hengstdal, the number of people with *Bijstand* – social assistance benefits – is 5%, while the national average is 2% (CBS, 2015; CBS, 2018E). The different scores on government benefits are shown in Figure 40. Thus, it can be concluded that Hengstdal has both more people with low incomes and in the *Bijstand* than on national average.

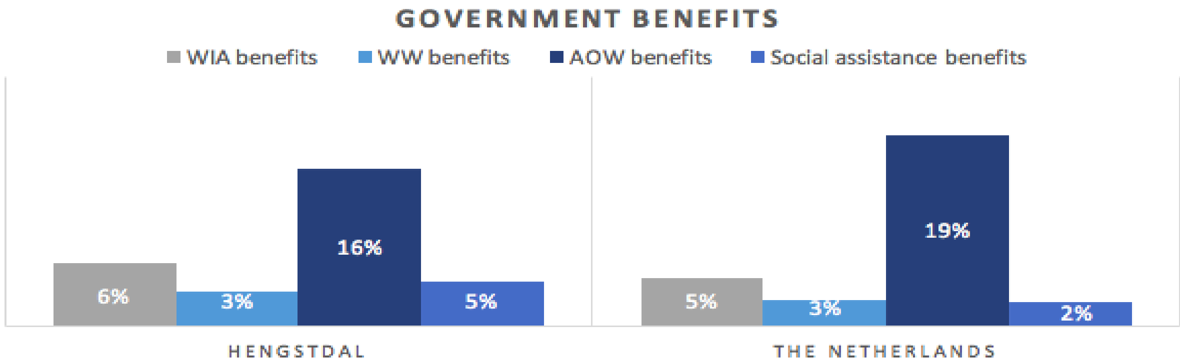


Figure 40. Distribution of government benefits of Hengstdal and the Netherlands (CBS, 2015; CBS, 2018E).

The district has a total of 3,459 homes, of which around 1900 are property of two housing corporations: *Standvast Wonen* and *Woningstichting De Gemeenschap* (Duurzaam Hengstdal, 2016). Then, 1200 houses are privately owned, and the rest is rented by other parties (CBS, 2016c). It can be concluded that there are significantly more houses owned by housing corporations in Hengstdal than in the Netherlands on average (CBS, 2017; CBS, 2016c).

The distribution is shown in Figure 41. It also shows the distribution of the homes of the housing corporations in Hengstdal: the red colored map are houses owned by *Standvast Wonen*, and the blue houses are owned by *de Gemeenschap*. The houses of *Standvast Wonen* are mostly located in the areas *Het rode Dorp* and the west part *de Bomenbuurt* (Duurzaam Hengstdal, 2016). The houses of *de Gemeenschap* are located in the east part of *de Bomenbuurt,* and the complete *Spoortbuurt* (Duurzaam Hengstdal, 2016.

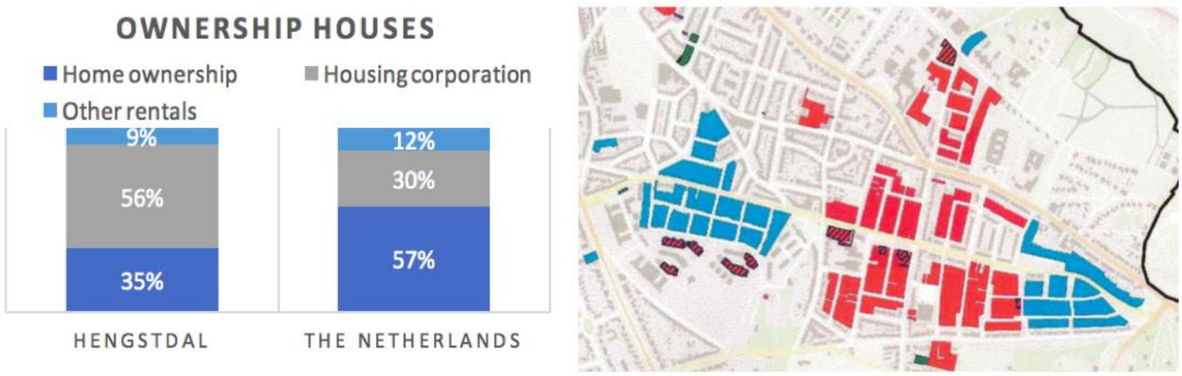


Figure 41. The distribution of the ownership of the houses (l) in Hengstdal and the Netherlands (CBS, 2017; CBS, 2016c). The distribution of houses owned by the cooperation (r) the red colored map are houses owned by Standvast wonen, and the blue houses are owned by de Gemeenschap (Duurzaam Hengstdal, 2016).

Appendix C – Content of the web tool

In this Appendix, a complete overview of all the content of the web tool is provided. It is in Dutch, because the web tool is designed for Hengstdal, a Dutch neighborhood.

Content of the introduction and instruction pages

Introductie

Nijmegen heeft de ambitie om in 2045 energieneutraal te zijn. De eerste stap om dit doel te bereiken, is het vervangen van aardgas in Hengstdal voor een duurzamer alternatief. Deze website is speciaal gemaakt in opdracht van de gemeente Nijmegen voor het onderzoek "*Hengstdal: Duurzame alternatieven voor aardgas*". Een onderzoeker van de Technische Universiteit Delft voert dit onderzoek uit in de vorm van een online experiment.

Omdat u een bewoner bent van de wijk Hengstdal in Nijmegen, willen wij u vragen om mee te doen aan dit experiment. De gemeente Nijmegen heeft dit experiment opgezet, omdat ze graag wil weten welke vorm van warmtevoorziening de voorkeur heeft van de bewoners van Hengstdal. Het experiment duurt ongeveer 15 tot 20 minuten. Al uw antwoorden en data worden volledig anoniem verwerkt en zullen nooit gerapporteerd worden op individueel niveau.

Instructie tekst

Om Nijmegen in 2045 energieneutraal te maken, moet Hengstdal de warmtevoorziening verduurzamen. Op de hoofdpagina krijgt u 16 alternatieven te zien die kunnen worden toegepast in de wijk Hengstdal. Niet alle alternatieven zorgen ervoor dat de warmtevoorziening volledig duurzaam zal worden.

De gemeente Nijmegen zou graag willen weten welk alternatief volgens u de beste optie is om de warmtevoorziening te verduurzamen. Om u te helpen bij uw keuze, zijn alle 16 alternatieven gescoord op meerdere kenmerken. Concreet vragen wij u om een alternatief te selecteren door op de 'selectieknop' te klikken. In de instructie video wordt dit verder toegelicht.

Extra informatie vooraf – pagina 1

Op de hoofdpagina kunt u kiezen uit 16 alternatieven. Deze alternatieven zijn ingedeeld op drie thema's:

Netwerk: aangesloten blijven op het aardgasnet, overstappen op een geheel elektrische oplossing, omschakelen naar een warmtenet met normale radiatoren/vloerverwarming.

Energiebron: contract afsluiten voor groene energie (elektriciteit, gas of warmte).

Isolatie: de optie om uw huis tot een hoog niveau te isoleren.

Extra informatie vooraf – pagina 2

De alternatieven zijn gescoord op 8 kenmerken, waarvan betaalbaarheid de eerste is. Of een alternatief betaalbaar is, kan alleen door uzelf bepaald worden. Om er zeker van te zijn dat er geen verwarring is over hoe de betaalbaarheid is berekend, wordt er hier een kort overzicht gegeven. Betaalbaarheid is de som van:

- De jaarlijkse energierekening van de hele wijk, verdeeld over het aantal bewoners.
- De kosten van de investeringen die nodig zijn voor het gekozen alternatief. Om de alternatieven goed te kunnen vergelijken, zijn deze kosten verdeeld over de jaren tot 2045.

De waarden die u straks ziet, zijn dus niet specifiek berekend voor uw eigen woning, maar een gemiddelde van de wijk.

Content of the information pages

Niets veranderen

Als u voor dit alternatief kiest, besluit u niet bij te dragen aan het doel om aardgas in Hengstdal te vervangen door een duurzamer alternatief. U blijft aardgas gebruiken voor het koken en verwarmen van uw huis. Ook kiest u ervoor geen isolatie te plaatsen, waardoor u geen investeringen hoeft te doen. Daarnaast zal u geen overlast ervaren door bijvoorbeeld de plaatsing van nieuwe installaties.

Wel moet u er rekening mee houden dat de kosten van het gebruik van aardgas gaan groeien, onder andere door een stijgende aardgasprijs. Ook zal Nederland, door het recente besluit om te stoppen met het oppompen van aardgas uit Groningen, meer gas moeten gaan importeren.

Biogas

In dit alternatief kiest u ervoor uw huis te verwarmen met biogas. Biogas ontstaat uit de vergisting van mest, gft en ander organisch afval. Met deze keuze draagt u bij aan het doel om aardgas in Hengstdal te vervangen door een duurzamer alternatief. Daarnaast zijn er geen nieuwe installaties nodig en u hoeft uw huidige fornuis niet te vervangen.

Omdat de prijs van biogas hoger is dan van aardgas, zullen de kosten van het verbruik stijgen. Ook is het een probleem dat er niet genoeg biogas beschikbaar is voor iedereen. Dus als u kiest voor dit alternatief, wordt Nederland afhankelijk van energie uit het buitenland. Over de beschikbaarheid van biogas kunt u hier meer lezen.

Isoleren tot energielabel A

In dit alternatief kiest u ervoor uw huis te isoleren tot energielabel A. Om dit energielabel te krijgen, moet u investeren in de isolatie van het dak, de vloer en de spouwmuren. Ook zal u het glas moeten vervangen door HR++ glas. Het jaarlijks gasverbruik, in Hengstdal gemiddeld 1400 m3, kunt u met deze isolatie verlagen tot 600 m3 per jaar.

Daarnaast kunt u het elektriciteitsverbruik verminderen door ledlampen en zeer zuinige huishoudelijke apparaten aan te schaffen. Door beide maatregelen gaat uw energieverbruik omlaag en worden de jaarlijkse kosten minder. Ook zal uw huis comfortabeler zijn, omdat isolatie tocht in het huis vermindert.

Biogas, isoleren tot energielabel A

In dit alternatief kiest u ervoor uw huis te verwarmen met biogas en om het te isoleren tot energielabel A. Met deze keuze draagt u bij aan het doel om aardgas in Hengstdal te vervangen door een duurzamer alternatief. Er zijn geen nieuwe installaties nodig en u hoeft niet uw huidige fornuis te vervangen.

Omdat de prijs van biogas hoger is dan van aardgas, zullen de kosten van het verbruik stijgen. Tegelijkertijd kiest u voor goede isolatie, waardoor uw huis minder energie nodig heeft, wat weer besparend werkt. Om energielabel A te krijgen, moet u investeren in de isolatie van het dak, de vloer en de spouwmuren. Ook zal u het glas moeten vervangen door HR++ glas. Uw huis zal hierdoor comfortabeler zijn, omdat isolatie tocht in het huis vermindert. Wel is het een probleem dat er niet genoeg biogas beschikbaar is voor iedereen. Dus als u kiest voor dit alternatief, wordt Nederland afhankelijk van energie uit het buitenland. Over de beschikbaarheid van biogas kunt u hier meer lezen.

Lucht warmtepomp met fossiele elektriciteit

Met dit alternatief kiest u ervoor om uw cv-ketel te vervangen door een elektrische lucht warmtepomp. Op zichzelf is deze pomp geen duurzamere optie. Het is pas een duurzamer alternatief als u bijvoorbeeld zonne- en windenergie gebruikt. De pomp haalt warmte uit de buitenlucht en gebruikt dit om het water tot 40 graden te verwarmen. Over dit onderwerp kunt u hier meer lezen.

Het water uit de warmtepomp is kouder dan het water uit een cv-ketel, waar het een temperatuur van 80 graden kan bereiken. Daarom heeft u met een warmtepomp meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. In dit alternatief kiest u ervoor geen extra isolatie te plaatsen, terwijl dit nodig is om het huis warm te houden. Hierdoor zal het oncomfortabel zijn in huis. Ook vervangt u in dit alternatief het koken op aardgas door koken op een inductieplaat.

Lucht warmtepomp met elektriciteit uit wind en zon

In dit alternatief kiest u ervoor om uw cv-ketel te vervangen door een elektrische lucht warmtepomp. Dit is een duurzamer alternatief, omdat u gebruik maakt van zonne- en windenergie. De warmtepomp haalt warmte uit de buitenlucht en gebruikt deze warmte om het water te verwarmen tot 40 graden. Over dit onderwerp kunt u hier meer lezen.

Het water uit de warmtepomp is kouder dan het water uit een cv-ketel, waar het een temperatuur van 80 graden kan bereiken. Daarom heeft u met een warmtepomp meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. In dit alternatief kiest u ervoor geen extra isolatie te plaatsen, terwijl dit nodig is om het huis warm te houden. Hierdoor zal het oncomfortabel zijn in huis. Ook vervangt u in dit alternatief het koken op aardgas door koken op een inductieplaat.

Lucht warmtepomp met fossiele elektriciteit en energie label A

In dit alternatief kiest u ervoor om uw cv-ketel te vervangen door een elektrische lucht warmtepomp. Op zichzelf is deze pomp geen duurzamere optie. Het is pas een duurzamer alternatief als u bijvoorbeeld zonne- en windenergie gebruikt. De warmtepomp haalt warmte uit de buitenlucht en gebruikt deze warmte om het water te verwarmen tot 40 graden. Over dit onderwerp kunt u hier meer lezen.

Het water uit de warmtepomp is kouder dan het water uit een cv-ketel, waar het een temperatuur van 80 graden kan bereiken. Daarom heeft u met een warmtepomp meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. Een oplossing hiervoor is het gebruik van vloerverwarming, waarbij buizen onder de vloer worden aangebracht. Er is dan, in combinatie met goede isolatie, genoeg verwarming beschikbaar om een comfortabele temperatuur te bereiken.

Ook vervangt u in dit alternatief het koken op aardgas door koken op een inductieplaat. Als laatste moet u rekening houden met eventuele geluidsoverlast. Een warmtepomp gebruikt namelijk een buitenunit die lucht van buiten opneemt.

Lucht warmtepomp met elektriciteit uit wind en zon en energie label A

In dit alternatief kiest u ervoor om uw cv-ketel te vervangen door een elektrische lucht warmtepomp. Dit is een duurzamer alternatief, omdat u gebruik maakt van Nederlandse zonne- en windenergie. De warmtepomp haalt warmte uit de buitenlucht en gebruikt deze warmte om het water te verwarmen tot 40 graden. Over dit onderwerp kunt u hier meer lezen.

Het water uit de warmtepomp is kouder dan het water uit een cv-ketel, waar het een temperatuur van 80 graden kan bereiken. Daarom heeft u met een warmtepomp meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. Een oplossing hiervoor is het gebruik van vloerverwarming, waarbij buizen onder de vloer worden aangebracht. . Er is dan, in combinatie met goede isolatie, genoeg verwarming beschikbaar om een comfortabele temperatuur te bereiken.

Ook vervangt u in dit alternatief het koken op aardgas door koken op een inductieplaat. Als laatste moet u rekening houden met eventuele geluidsoverlast. Een warmtepomp gebruikt namelijk een buitenunit die lucht van buiten opneemt.

Stadsverwarming met vloerverwarming en warmte van gascentrale

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming. Stadsverwarming is op zichzelf geen duurzame optie. Het wordt pas een duurzamer alternatief als er gebruik wordt gemaakt van bijvoorbeeld de restwarmte van een afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

De temperatuur van het water uit de stadsverwarming is niet hoger dan 40 graden, terwijl het water uit een cv-ketel een temperatuur van 80 graden kan bereiken. Hierdoor bespaart u energie. Maar omdat het water uit de stadsverwarming kouder is, heeft u wel meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. In dit alternatief kiest u ervoor geen extra isolatie te plaatsen, terwijl dit nodig is om uw huis warm te houden. Hierdoor zal het huis oncomfortabel zijn. Daarnaast vervangt u in dit alternatief het koken op aardgas door het koken op een inductieplaat.

Stadsverwarming met vloerverwarming en warmte van afvalenergiecentrale

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming, waarbij een afval energiecentrale het warme water produceert. Dit is een duurzamer alternatief, omdat er gebruik wordt gemaakt van de restwarmte van de afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

De temperatuur van het water uit de stadsverwarming is niet hoger dan 40 graden, terwijl het water uit een cv-ketel een temperatuur van 80 graden kan bereiken. Hierdoor bespaart u energie. Maar omdat het water uit de stadsverwarming kouder is, heeft u wel meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. In dit alternatief kiest u ervoor geen extra isolatie te plaatsen, terwijl dit nodig is om uw huis warm te houden. Hierdoor zal het huis oncomfortabel zijn. Daarnaast vervangt u in dit alternatief het koken op aardgas door het koken op een inductieplaat.

Stadsverwarming met vloerverwarming en warmte van gascentrale en energie label A

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming. Dit is op zichzelf geen duurzame optie. Het wordt pas een duurzamer alternatief als er gebruik wordt gemaakt van bijvoorbeeld de restwarmte van een afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

De temperatuur van het water uit de stadsverwarming is niet hoger dan 40 graden, terwijl het water uit een cv-ketel een temperatuur van 80 graden kan bereiken. Hierdoor bespaart u energie. Maar omdat het water uit de stadsverwarming kouder is, heeft u wel meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. Een oplossing hiervoor is het gebruik van vloerverwarming, waarbij buizen onder de vloer worden aangebracht. Er is dan, in combinatie met goede isolatie, genoeg verwarming beschikbaar om een comfortabele temperatuur te bereiken. Ook vervangt u in dit alternatief het koken op aardgas door het koken op een inductiekookplaat.

Stadsverwarming met vloerverwarming en warmte van afval energiecentrale en energie label A

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming, waarbij een afval energiecentrale het warme water produceert. Dit is een duurzamer alternatief, omdat er gebruik wordt gemaakt van de restwarmte van de afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

De temperatuur van het water uit de stadsverwarming is niet hoger dan 40 graden, terwijl het water uit een cv-ketel een temperatuur van 80 graden kan bereiken. Hierdoor bespaart u energie. Maar omdat het water uit de stadsverwarming kouder is, heeft u wel meer verwarmingselementen nodig om uw huis op dezelfde temperatuur te krijgen. Een oplossing hiervoor is het gebruik van vloerverwarming, waarbij buizen onder de vloer worden aangebracht. Er is dan, in combinatie met goede isolatie, genoeg verwarming beschikbaar om een comfortabele temperatuur te bereiken. Ook vervangt u in dit alternatief het koken op aardgas door het koken op een inductiekookplaat.

Stadsverwarming met normale verwarming en warmte van gascentrale

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming, waarbij de temperatuur van het water, vergelijkbaar met de cv-ketel, rond de 80 graden ligt. Stadsverwarming is op zichzelf geen duurzame optie. Het zal pas een duurzamer alternatief zijn als er bijvoorbeeld gebruik gemaakt wordt van de restwarmte van een afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

Door de hoge temperatuur van het water, kunt u gebruik blijven maken van normale radiatoren. Het is ook niet noodzakelijk om te isoleren, maar hierdoor verbruikt u wel meer energie. Daarnaast vervangt u, in dit alternatief, het koken op aardgas door het koken op een inductiekookplaat.

Stadsverwarming met normale verwarming en warmte van afvalenergiecentrale

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming, waarbij de temperatuur van het water, vergelijkbaar met de cv-ketel, rond de 80 graden ligt. Een afval energiecentrale produceert het warme water. Dit is een duurzamer alternatief, omdat er gebruik wordt gemaakt van de restwarmte van de afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

Door de hoge temperatuur van het water, kunt u gebruik blijven maken van normale radiatoren. Het is ook niet noodzakelijk om te isoleren, maar hierdoor verbruikt u wel meer energie. Daarnaast vervangt u, in dit alternatief, het koken op aardgas door het koken op een inductiekookplaat.

Stadsverwarming met normale verwarming en warmte van gascentrale en energie label A

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming, waarbij de temperatuur van het water, vergelijkbaar met de cv-ketel, rond de 80 graden ligt. Stadsverwarming is op zichzelf geen duurzame optie. Het zal pas een duurzamer alternatief zijn als er bijvoorbeeld gebruik gemaakt wordt van de restwarmte van een afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

Door de hoge temperatuur van het water, kunt u gebruik blijven maken van normale radiatoren. De isolatie van het huis verlaagt uw energieverbruik en verhoogt uw comfort in huis. Ook vervangt u in dit alternatief het koken op aardgas door het koken op een inductiekookplaat.

Stadsverwarming met normale verwarming en warmte van afval energiecentrale en energie label A

In dit alternatief kiest u ervoor om gebruik te maken van stadsverwarming, waarbij de temperatuur van het water, vergelijkbaar met de cv-ketel, rond de 80 graden ligt. Een afval energiecentrale produceert het warme water. Dit is een duurzamer alternatief, omdat er gebruik wordt gemaakt van de restwarmte van de afvalenergiecentrale. Over dit onderwerp kunt u hier meer lezen.

Door de hoge temperatuur van het water, kunt u gebruik blijven maken van normale radiatoren. De isolatie van het huis verlaagt uw energieverbruik en verhoogt uw comfort in huis. Ook vervangt u in dit alternatief het koken op aardgas door het koken op een inductiekookplaat.

Extra informatie voor warmtepomp

(Bron: HIERVerwarmt)

Een warmtepomp bestaat uit een binnen- en buitengedeelte. De lucht stroomt door het buitengedeelte van de warmtepomp en werkt als volgt:

In het buitendeel van de warmtepomp zit een vloeistof met een heel laag kookpunt. De buitenlucht is warmer dan deze vloeistof, zelfs in de winter, en geeft daarom warmte af aan de vloeistof. De vloeistof gaat koken vanwege het lage kookpunt en verdampt.

De damp wordt opgevangen in het binnen gedeelte van de warmtepomp. Daar wordt het 'samengeperst' met een compressor. Door het verhogen van de druk gaat de temperatuur stijgen tot 40 graden. Bijna alle elektriciteit die een warmtepomp verbruikt, wordt gebruikt in dit proces.

Vervolgens wordt met deze samengeperste warmte het water verwarmd dat gebruikt wordt voor de centrale verwarming van uw huis. De warmte wordt eerst opgeslagen in een (buffer)vat. Van daaruit wordt het door uw huis verspreid via speciale radiatoren of wand- en vloerverwarming, net zoals uw cv-ketel dat nu doet.

Als de warmte is afgegeven aan de centrale verwarming, stroomt de afgekoelde vloeistof weer naar het buitendeel van de warmtepomp. Hier begint het proces weer bij stap 1.

Extra informatie voor biogas

(Bron: HIERVerwarmt)

Op het moment is er niet genoeg biogas beschikbaar om dit op grote schaal toe te voegen aan de gasnetten. Daarnaast groeit de vraag naar biogas ook vanuit de industrie, omdat deze sector behoefte heeft aan een groene alternatieve brandstof.

Door de beperkte beschikbaarheid, is de verwachting dat huizen alleen biogas kunnen gebruiken als de andere alternatieven niet geschikt zijn. Denk hierbij aan woningen die lastig te isoleren zijn, of wijken waar het niet mogelijk is om een nieuw netwerk aan te leggen. Woningen in buitengebieden, historische stadscentra en monumentale panden zijn hier goede voorbeelden van.

Als de vraag naar biogas groter is dan de productie, zal Nederland biogas moeten gaan importeren.

Extra informatie voor stadsverwarming uit een afval energiecentrale

(Bron: Afval energiecentrale ARN B.V.)

De Afval energiecentrale ARN B.V. in Nijmegen produceert warm water voor de huizen in Nijmegen, die aangesloten zijn op de stadsverwarming, door gebruik te maken van de restwarmte van de centrale.

Het verbranden van afval zorgt ervoor dat er warmte vrijkomt. Een deel van die energie zet de ARN in voor de productie van groene elektriciteit. De overige energie warmt het water op voor de stadsverwarming. Op deze manier hangt de energieproductie niet af van fossiele brandstoffen en wordt het dus gezien als een duurzame energiebron.

Constraint: Percentage duurzame energiebronnen

Het percentage duurzame energie dat opgewekt wordt voor het energiegebruik. Eenheid: [%]

Attribuut 1: Betaalbaarheid

De gemiddelde kosten van de energierekening en investeringen per huishouden per jaar. Eenheid: [€/huishouden/jaar]

Attribuut 2: Betrouwbaarheid

Het niveau van betrouwbaarheid van de energievoorziening, 1 is erg onbetrouwbaar en 5 het huidige niveau, dat zeer betrouwbaar is. Eenheid [1-5 betrouwbaarheidsniveau]

Attribuut 3: Beschikbaarheid

Nederlandse afhankelijkheid van geïmporteerde energie in procenten. Eenheid: [%]

Attribuut 4: Werkgelegenheid

Groei/krimp aantal banen ten opzichte van het bestaand aantal banen. Eenheid: [+ % banen erbij]

Attribuut 5: Veiligheid

Het landelijk aantal direct incidenten per jaar gerelateerd aan het gekozen alternatief. Eenheid: [aantal landelijke incidenten/jaar]

Attribuut 6: Comfort

Het niveau van comfort van het binnenklimaat, 1 is een negatieve score, 5 een positieve score, 3 is het huidige comfort niveau in de meeste woningen. Eenheid [1-5 comfort niveau]

Attribuut 7: Geluidsoverlast

Of er waarschijnlijk geluidsoverlast veroorzaakt wordt door de vervanging/onderhoud van het netwerk. Eenheid: [Waarschijnlijk geluidsoverlast- geen geluidsoverlast]

Attribuut 8: CO_2-uitstoot

De besparing CO_2-uitstoot ten opzichte van 2016 in procenten. [% CO_2]

Content of the delegation page

Delegeren

Wij bieden u de mogelijkheid om uw beslissing in dit experiment over te dragen aan:

De andere deelnemers aan dit experiment.

De experts van de gemeente.

De andere deelnemers aan het experiment

De bewoners van Hengstdal zijn benaderd om mee te doen aan dit experiment. U heeft de optie om uw beslissing over te dragen aan de andere deelnemers. In dat geval adviseert u de gemeente om te kiezen voor het alternatief dat uit het experiment naar voren komt en het best aansluit bij de voorkeur van de bewoners van Hengstdal.

Experts

U kunt uw keuze ook overlaten aan experts van de gemeente. In dat geval adviseert u de gemeente om experts te raadplegen en in samenwerking met deze experts een duurzaam alternatief voor aardgas te kiezen.

Content of the follow-up questions

U hebt zojuist de gemeente Nijmegen geadviseerd om te kiezen voor het volgende alternatief. Kunt u aangeven waarom u voor dit alternatief hebt gekozen?

1. Motivatie___
2. Hieronder volgen een aantal stellingen. Zou u per stelling kunnen aangeven in hoeverre u het met de stelling eens bent?
    a. Ik ben overtuigd van mijn keuze.

i. Geheel mee eens
ii. Mee eens
iii. Neutraal
iv. Mee oneens
v. Geheel mee oneens

b. Ik vind dit een realistisch experiment.
c. Geheel mee eens
d. Mee eens
e. Neutraal
f. Mee oneens
g. Geheel mee oneens

3. Ik vind het een goede zaak dat de gemeente Nijmegen burgers probeert te betrekken bij het maken van keuzes tussen alternatieven voor aardgas.
   a. Geheel mee eens
   b. Mee eens
   c. Neutraal
   d. Mee oneens
   e. Geheel mee oneens
4. Dit experiment biedt de gemeente Nijmegen relevante informatie bij het maken van keuzes tussen alternatieven.
   a. Geheel mee eens
   b. Mee eens
   c. Neutraal
   d. Mee oneens
   e. Geheel mee oneens
5. Wat is uw postcode?
   a. ____ __
6. Bent u van plan om in de komende vijf jaar te verhuizen naar een plaats buiten de buurt Hengstdal?
   a. Nee
   b. Ja
7. Heeft u groene energie?
   a. Ja, duurzame elektriciteit
   b. Ja, duurzame elektriciteit en gecompenseerd gas
   c. Nee

   d. Ja, anders ____
   e. Weet ik niet
8. Hoe verwarmt u uw huis?
   a. Individuele cv-ketel
   b. Elektrische warmtepomp
   c. Stadsverwarming
   d. Anders ___
   e. Weet ik niet
9. Wat is het energielabel van uw huis?
   a. A+
   b. A
   c. B
   d. C
   e. D
   f. E
   g. F
   h. G
   i. Weet ik niet
10. In welk jaar is uw huis gebouwd?
   a. - - -
   b. Weet ik niet
11. Wat gebruikt u voor het koken?
   a. Gaskookplaat
   b. Elektrische kookplaat
   c. Keramische kookplaat
   d. Inductiekookplaat
   e. Weet ik niet

Appendix D – Detailed explanation of use of Energy Transition Model

In this Appendix, it is explained how the ETM is used in this thesis to investigate the impact of each alternative on the future of Hengstdal's energy system in the year 2045. The energy system used in the ETM, shown on the left of Figure 42, consists of four main parts: the energy **demand** from the final energy consumers (households, buildings, transport, industry, agriculture and other), the energy **supply** with the different types of energy production, an **electricity balance** where the electricity network can be regulated, and the energy **costs**, where predictions can be added on expected price changes.

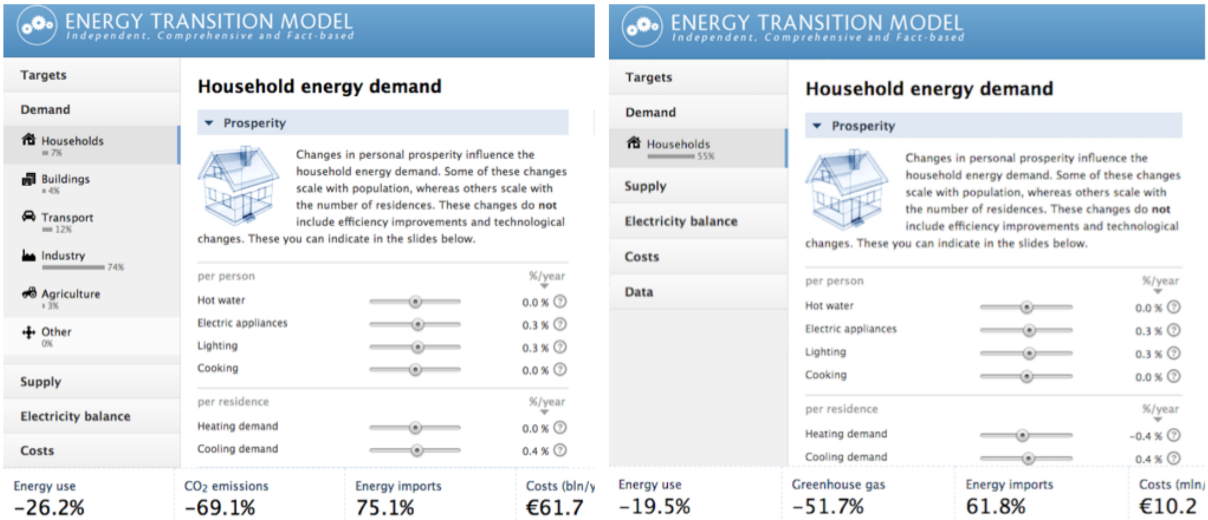


Figure 42. The energy system used in the ETM consists of four main parts: the energy demand, the energy supply, the electricity balance and the energy costs (l). The adapted energy system of the ETM, with the omission of all other final energy consumers except households (r).

For the purpose of this thesis, the Hengstdal district was added to the geographical regions database. Additionally, due to the focus of this research on the effects of the alternatives on the households – and in order to simplify – all other final energy consumers were omitted. The adapted energy system of the ETM is shown on the right of Figure 42.

In order to apply the ETM correctly, the workings of the ETM are first presented. The core idea of the ETM is that the future will be equal to the present, unless changes take place. Therefore, it only contains information about two scenarios:

1. The start-scenario. This scenario is fixed and is used as the baseline against which the effects of future policy choices are measured, e.g. in terms of reduction of CO_2 emissions.
2. The future scenario. This scenario is initially identical to the start-scenario but then shows the evolution of its variables. The changes of the variables are made in the ETM through the use

of the sliders (see Figure 43 for an example of a slider). These changes are based on assumptions about the future energy system.

First the construction of the start-scenario will be described in Paragraph 0. Then, in Paragraph 0, it is explained how the future scenario is constructed based on the assumptions about how the energy system will change. In Paragraph 0, an existing scenario is used as a baseline for these assumptions. In Paragraph 0, the national scale of the baseline scenario is adapted to the scale of Hengstdal. The last step is to create 16 different scenarios for each alternative, which will be done in Paragraph 0.

The start-scenario

The first step is to construct the start scenario, which is the present-day energy system of Hengstdal. To start, the ETM asks to select a region – the district Hengstdal – and a future year – which is the year 2045 for the purpose of this thesis. Then, the demographic data about Hengstdal – if available – and otherwise demographic data about Nijmegen or the Netherlands is used to construct the present-day energy system of the district. The demographic data consists of, for example, the current population of Hengstdal (see Figure 43 left), the number of houses built before and after 1992 – an indicator for the level of insulation – and the average energy demand of the district. An overview of the data can be found in Chapter 7 – the paragraph about the residents of Hengstdal (7.4) and the house ownership in Hengstdal (7.5) – and in Chapter 8 – the energy system of Hengstdal (8.3).

The future scenario

The second step is construct the future scenario. Assumptions must be entered on how the present-day energy system will change in the future. In the ETM, sliders are used to indicate the assumptions on expected change for each variable. An example of a slider can be seen in Figure 43, which shows the variable "population of Hengstdal" before and after the use of the slider. On the left, it shows the present-day scenario: currently, there are 7,040 people living in Hengstdal (CBS, 2016). On the right, it shows the expected change over the years – the predicted population growth between 2018 and 2045 is around 22.6% – which leads to an expected total of 8,630 residents in 2045 (CBS, 2015).

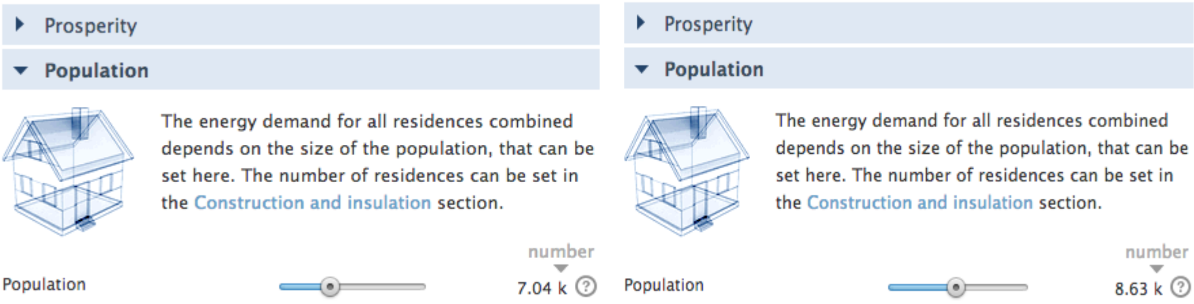


Figure 43. Example of a slider in the Energy Transition Model

In general, assumptions on how the energy system will change in the future are combined in scenarios. The ETM provides the possibility to design a specific scenario for each energy system-related project. However, due to the fact that there are more than 300 variables in the ETM, it is outside the scope of this thesis to individually carry out the required research that is needed for each of these variables.

Therefore, the assumptions from an existing scenario will be used as a starting point and from there the scenario will be customized accordingly, in order to create a suitable scenario with assumptions that are applicable to the future of the energy system of Hengstdal.

Selection of an existing scenario as baseline

The next step is to select an existing scenario, which can be used as a base for the assumptions. Quintel Intelligence developed several scenarios. However, the majority of them only provides predictions until the year 2030. There are only two scenarios available that were designed for 2050, both developed in 2014 in cooperation with the Council for the Environment and Infrastructure, following a commission by the Ministry of Economic Affairs. The scenarios were developed to answer whether – and how – it is possible to achieve an 80% or 95% CO_2 reduction by 2050 in the Netherlands, when compared to 1990 (Quintel Intelligence, 2015). It should be pointed out that the two scenarios contain assumptions on two parts:

- The future of the Netherlands in 2050, e.g. demographic changes.
- The policy decisions that are made to achieve the 80% or 95% CO_2 reduction.

These two parts can be classified into two different types of variables: external and internal variables. Each part will be discussed briefly.

The first part of the assumptions is based on external variables, which are, for example, the population growth or price development of an energy technology. The values of these variables cannot be influenced directly by new policies, for example. Therefore, these variables, if forecasted correctly, will be the same for any scenario about the future of the Netherlands in 2050. Therefore, the values of the external variables in these scenarios, such as the predictions of the costs, are also suitable to be applied in the scenario specifically designed for Hengstdal.

Nevertheless, in order to research the effect of each alternative on the future of Hengstdal's energy system in the year 2045 – set by the municipality of Nijmegen as final year to finish the natural gas-free transition in Nijmegen – a scenario about the future of that specific district – rather than the Netherlands as a whole – is needed. Therefore, it should be checked whether the adopted external variables are also applicable to Hengstdal's energy system in 2045 and, if not, adjustments must be made. This will be discussed in Paragraph 0.

The second part of the assumptions is based on internal variables, which could be, for example, a decision to install solar panels on all roofs, or to rapidly decrease the extraction of natural gas from the Groningen gas field. Installing solar panels on all roofs can be used as a policy instrument to achieve either an 80% or 95% CO_2 reduction in the Netherlands in 2050 (compared to 1990). The amount of extracted natural gas from the Groningen gas field is also an internal variable, which can be used as a policy instrument. However, as explained in the introduction, many decisions regarding energy policies, such as the plan to completely stop extracting natural gas from Groningen, have been announced recently. However, negotiations are still ongoing and the outcomes are still uncertain on many of these policies. Therefore, it is decided to not incorporate any of the recent announcements about policies in the assumption.

Moreover, in this thesis, the ETM is used to explore a different type of question: what is the effect of each alternative on the future of the energy system in Hengstdal in 2045? Different sets of internal variables, specifically determined for each of the sixteen alternatives, are needed to this end. These scenarios will be discussed in Paragraph 0.

Adjust the scale of the scenario

Now that an existing scenario is chosen, the next step is to check whether the adopted external variables are also applicable to Hengstdal's energy system and – if not – adjustments must be made.

First of all, as pointed out in Paragraph 8.2.1, Hengstdal does not have any indigenous production of energy and is thus fully dependent on the energy produced elsewhere in the country. However, the ETM models the energy system of Hengstdal as self-sufficient, so as if it was not dependent on the rest of the Netherlands. This is one of the limitations of the model that could lead to an unrealistic scenario.

A solution for this problem, suggested by Quintel Intelligence, is to place a scaled energy park in Hengstdal, which resembles the mix of energy produced on national level, but scaled down to Hengstdal's demand. In this way, Hengstdal is no longer completely dependent on imported energy and, at the same time, it is not necessary to model the whole energy system of the Netherlands.

Another problem regarding the use of these scenarios should be addressed. Both scenarios are forecasting the year 2050, not 2045. However, scenario designing is a complex and time-consuming process: each variable develops differently through the course of time. To individually alter each assumption accordingly is outside the scope of this work. Therefore, the same assumptions for the external variables used for 2050 will considered valid also in 2045.

Create different scenarios for each alternative

There are sixteen alternatives, which means that sixteen separate scenarios should be developed. However, as explained in Chapter X, each alternative exists out of three parts: the level of insulation and the efficiency of the lightning and the appliances, the type of network and installation and the relative energy source (renewable or fossil). The same structure is also used to compose each scenario. The level of insulation and the efficiency of the lightning and appliances is discussed first, then each type of network (gas, electricity, high temperature heating and low temperature heating) with both types of energy sources (renewable and fossil) is reviewed.

The level of insulation and the efficiency of the lightning and appliances

The level of insulation can be regulated in the construction and insulation part of the ETM. The ETM distinguishes between houses built before and after 1992. The data from Chapter 7 is used as input for this distribution. The ETM uses the R-value, which indicates how well the material resists conductive flows of heat. The higher the number, the better the insulation. According to the ETM, houses built before 1992 without any extra insulation have an R-value of 0.5 m^2K/W. Houses built after 1992 without additional insulation, instead, have an R-value of 1.8 m^2K/W. These settings are kept at the same level for all alternatives where no additional insulation is required. These settings are shown on the left of Figure 44.

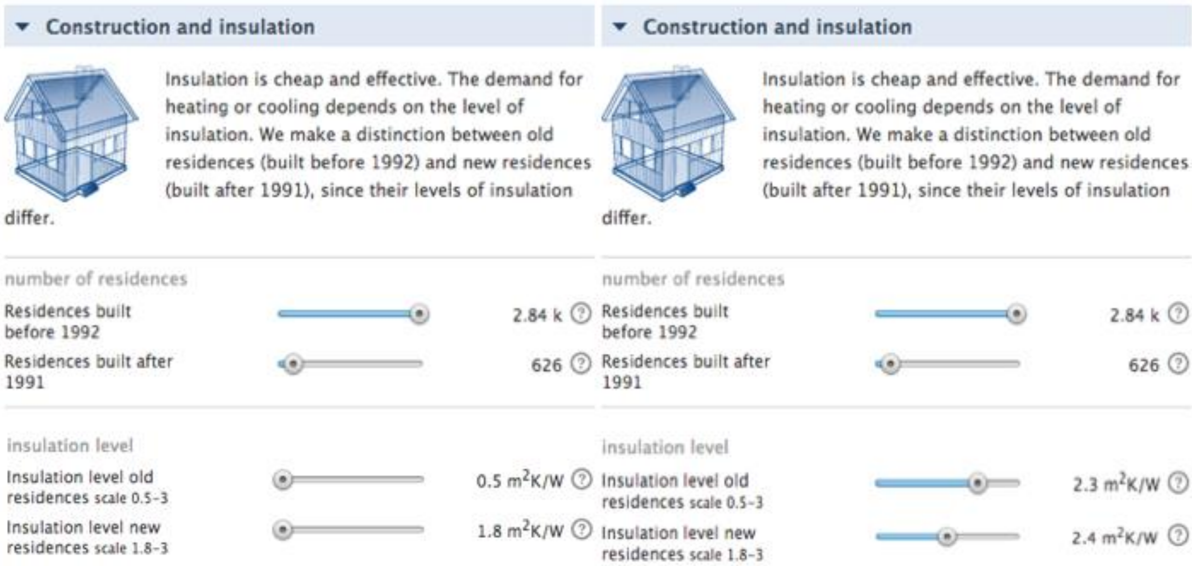


Figure 44. The settings of the ETM for the scenarios without insulation(r). The settings in the ETM for the scenarios with insulation (l).

The study of WoonConnect, which was introduced in the previous chapter, is used to determine the impact of insulating the houses in Hengstdal to energy label A (2017). The insulation of houses which are built before 1992 results in a reduction of the energy consumption of 63% (WoonConnect, 2017). The insulation of houses which are built after 1992, instead, results in a reduction of the energy consumption of 18% (WoonConnect, 2017). However, the relation between the R-value and the energy consumption is not linear, which makes it difficult to determine what the new R-values should be. Quintel Intelligence suggested to adjust the sliders of the R-values separately and monitor the effects on the heating demand. This led to the following results: with an R-value of 2.3 m^2K/W, the heating demand, for houses built before 1992, decreased by 63%. And with an R-value of 2.4 m^2K/W, the heating demand, for houses built after 1992, decreased by 18%. Both values are shown on the right of Figure 44.

The efficiency level of the lightning and appliances can be found in the lightning and appliances part of the ETM. The sliders in this part are less difficult to set. For those scenarios without efficient lightning and appliances, the sliders of the present-day energy system are set at the same level, as shown on the left of Figure 45 and Figure 46. For the other scenarios, the sliders reflect the measures that achieve the highest efficiency: 100% LED and A+++ appliances. The settings of the sliders are shown on the right of Figure 45 and Figure 46.

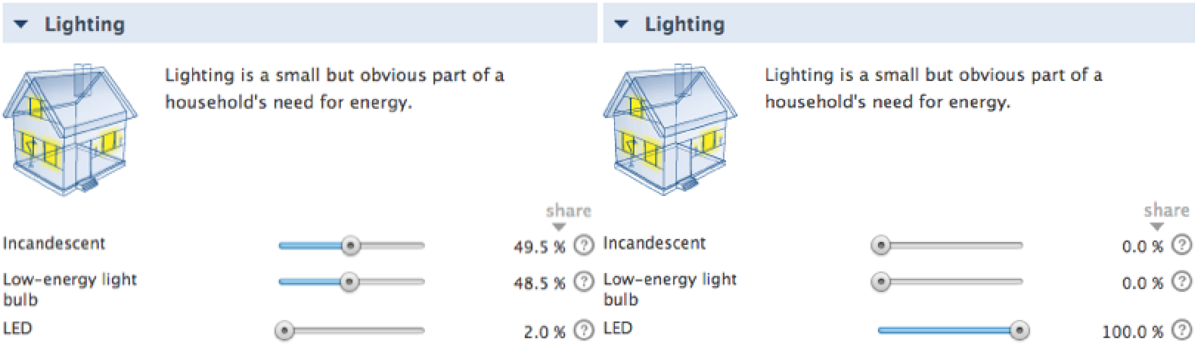


Figure 45. The settings of the ETM for the scenarios without efficient lightning (r). The settings in the ETM for the scenarios with efficient lightning (l).

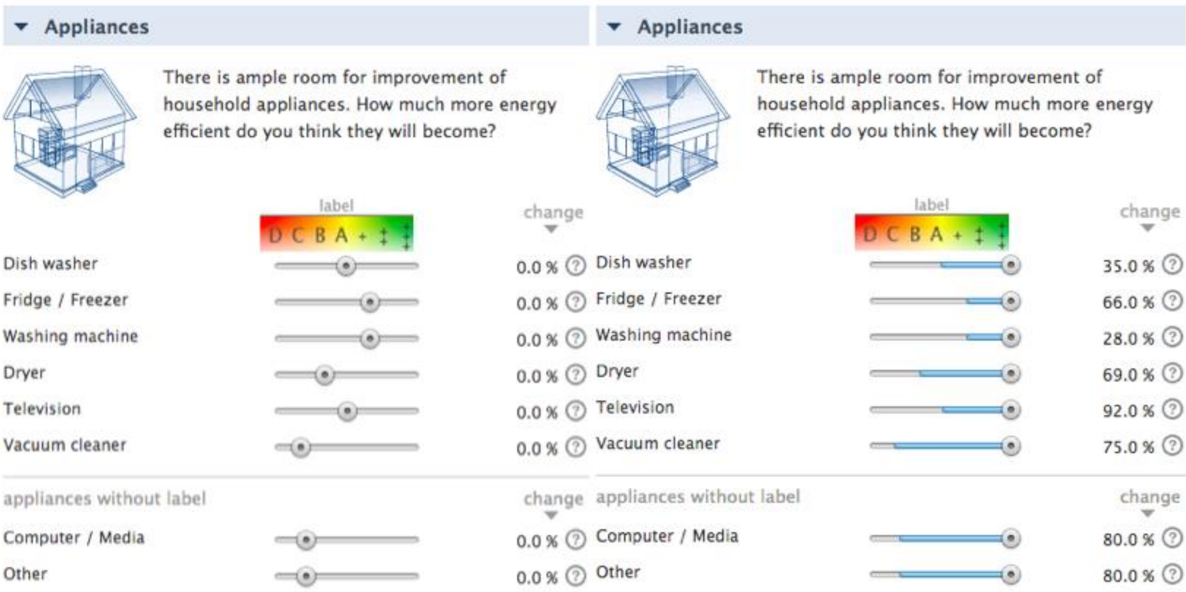


Figure 46. The settings of the ETM for the scenarios without efficient appliances (l). The settings in the ETM for the scenarios with efficient appliances (r).

Gas

For the scenarios where either natural gas or biogas is used, no changes have to be made to the current network and installations. Therefore, it is assumed that the settings of the present-day energy system are sufficient regarding both the network and the installations. However, for those scenarios where biogas and renewable electricity are used, the settings must be changed. First of all, the composition of the gas in the network is adjusted to 100% biogas. This is shown in Figure 47.

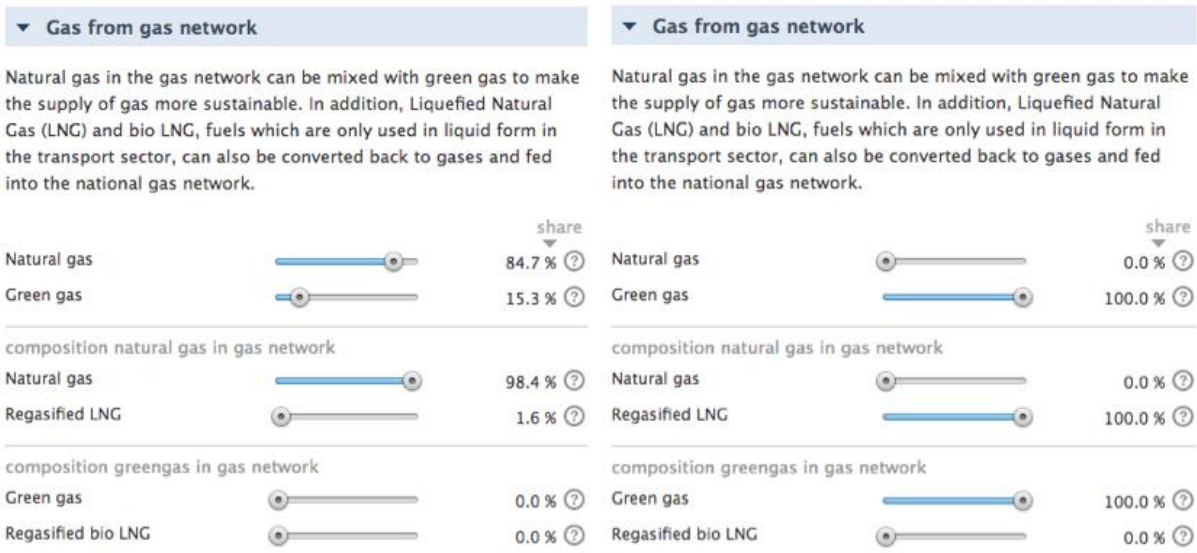


Figure 47. The settings of the ETM of the scenarios with natural gas (r). The settings in the ETM for the scenarios with biogas (l).

Additionally, renewable sources replace the current production of electricity. In these scenarios, solar power and onshore wind power are used to fulfill the demand for electricity. For biogas without insulation more energy is demanded than for biogas with insulation. Therefore, the number of PV panels, solar thermal collectors and onshore wind power is higher for biogas without insulation. The energy mix of each scenario is shown in Table 12.

ENERGY MIX	NATURAL GAS	BIOGAS	BIOGAS WITH INSULATION
Percentage of available surface with PV panels	3.1	50	30
Percentage of available surface with solar thermal collectors	2.4	50	30
Number of pulverized coal plants	0.00049	0	0
Number of pulverized coal plants with co-firing	0.00015	0	0
Number of gas CCGT plans	0.00258	0	0
Number of nuclear conventional power plants	0.00002	0	0
Number of onshore wind power turbines	0.08886	1.1	0.4

Table 12. The energy mix for the scenarios with natural gas, biogas and biogas with insulation.

Electricity

For the scenarios with an air heat pump, changes should be made in the settings for the installations and network. The air heat pump will be used for space heating, hot water and cooling. Additionally, cooking on gas is replaced with cooking on induction. All settings are shown in Figure 48.

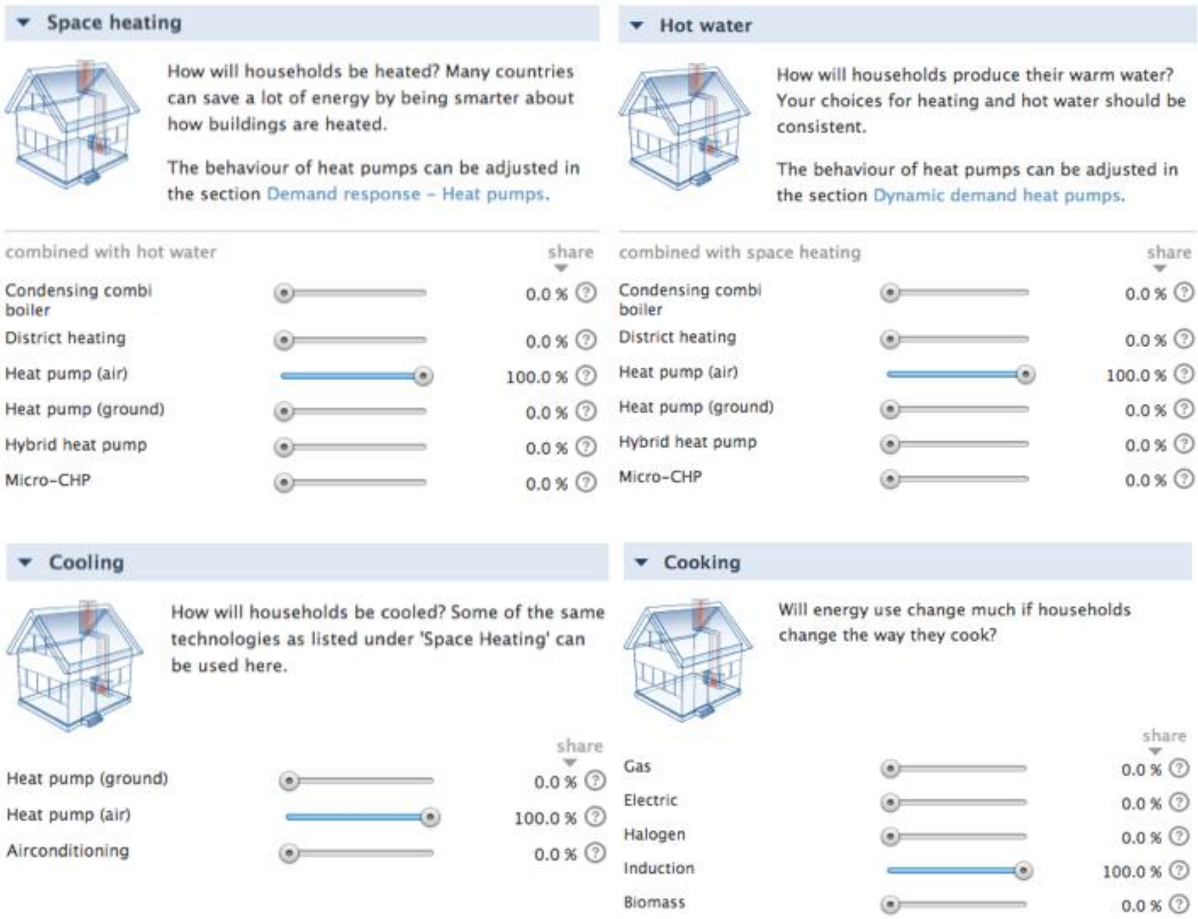


Figure 48. The settings of the ETM for the installations of the scenarios with an air heat pump.

For the alternatives that include renewable electricity, the settings for the energy production need to be changed. Renewable sources need to replace the fossil resources on which the current production of electricity depends. In these scenarios, solar power and onshore wind power are used to fulfill the demand for electricity. For air heat pumps without insulation more energy is demanded than for air heat pumps with insulation. Therefore, the number of PV panels, solar thermal collectors and onshore wind power is higher for the scenarios without insulation. The energy mix of the scenarios is shown in Table 13.

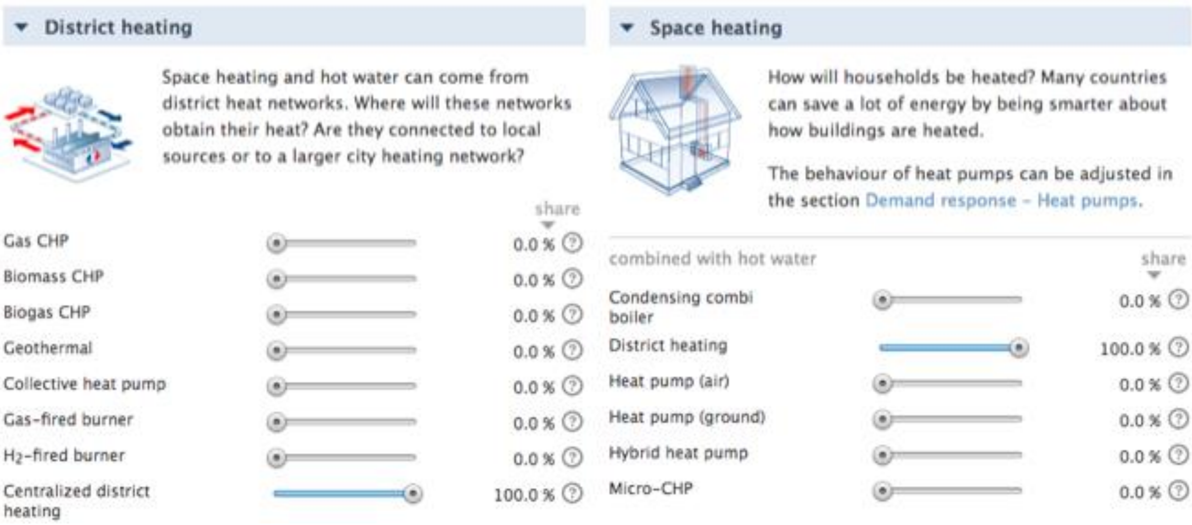
ENERGY MIX	FOSSIL ELECTRICITY	RENEWABLE ELECTRICITY	REN. ELEC. WITH INSULATION
Percentage of available surface with PV panels	3.1	100	30
Percentage of available surface with solar thermal collectors	2.4	100	30
Number of pulverized coal plants	0.00049	0	0
Number of pulverized coal plants with co-firing	0.00015	0	0
Number of gas CCGT plans	0.00258	0	0
Number of nuclear conventional power plants	0.00002	0	0
Number of onshore wind power turbines	0.08886	1.9	1.1

Table 13. The energy mix for the scenarios with air heat pump with fossil electricity, renewable electricity and renewable electricity with insulation.

Moreover, in these scenarios where air heat pumps run only on electricity, the connection to the gas network is no longer required. In general, this means that there is a much higher demand for electricity than before. The interconnector capacity is sufficient for the scenarios with fossil electricity because the production is very stable. However, in those scenarios where only renewable electricity is used, the interconnector capacity must be increased. The production of renewable electricity is less reliable, which means that it could occur that during peak hours, when the demand is the highest, not enough electricity is available. This means that suddenly a lot of electricity needs to be imported. Therefore, the interconnector capacity must be increased for both scenarios. For the scenario with the air heat pump without insulation, the demand for electricity is higher, which means that the capacity is increased from 1.65 MW to 8.8 MW. For the scenario with both the air heat pump and the insulation the capacity is also increased to 3.8 MW.

High temperature heating

For the scenarios that use high temperature heating, the settings of space heating, cooking and hot water should be set on district heating. The heat that is used in the district heating is centralized. All settings are shown in Figure 49.



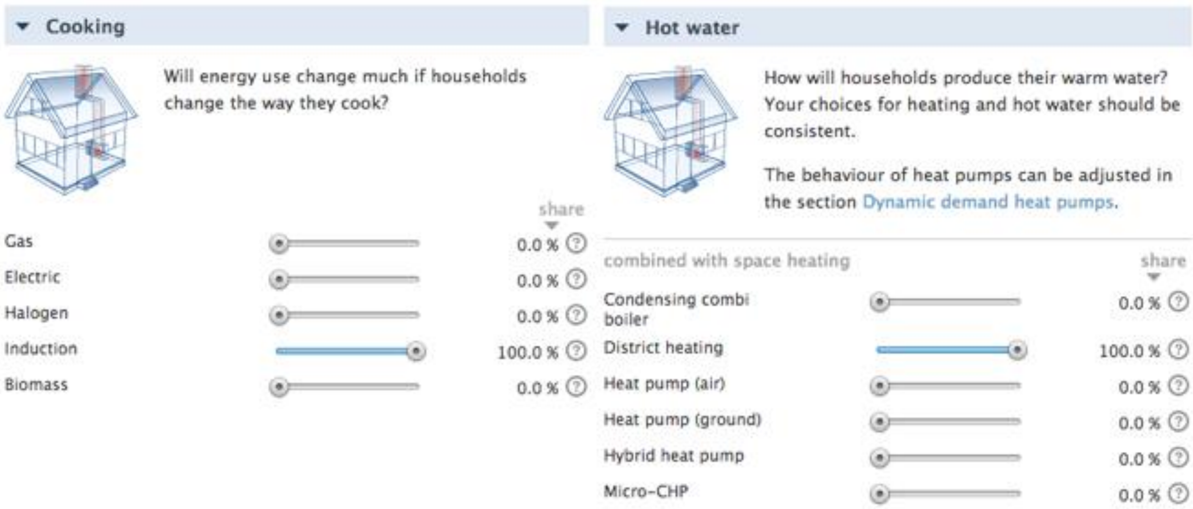


Figure 49. The settings of the ETM for the network of the scenarios with a connection the network for district heating.

In the alternatives with district heating, either a gas-fired plant or an incinerator is used to fulfill the demand for heat. Additionally, renewable sources replace the current production of electricity. In these scenarios, solar power and onshore wind power are used to fulfill the demand for electricity. For air heat pumps without insulation more energy is demanded than for air heat pumps with insulation. Therefore, the number of PV panels, solar thermal collectors and onshore wind power is higher for the scenarios without insulation. The energy mix of the scenarios is shown in Table 14.

ENERGY MIX	FOSSIL ENERGY	RENEWABLE ENERGY	REN. ENERGY WITH INSULATION
Number of Central gas-fired heater plants	0.1	0	0
Number of Central waste-fired heater plants	0	2.6	2.6
Percentage of available surface with PV panels	3.1	50	30
Percentage of available surface with solar thermal collectors	2.4	50	30
Number of pulverized coal plants	0.00049	0	0
Number of pulverized coal plants with co-firing	0.00015	0	0
Number of gas CCGT plans	0.00258	0	0
Number of nuclear conventional power plants	0.00002	0	0
Number of onshore wind power turbines	0.08886	1.1	1.3

Table 14. The energy mix for the scenarios with district heating with heat from a fossil source, renewable energy source and renewable energy source with insulation.

Low temperature heating

For the last four scenarios, with low temperature heating, the same settings are used as for the scenarios with high temperature heating. These settings can be found in Figure 49 and in Table 14. However, there is one main difference: low temperature heating demands 15% less energy than high temperature heating. Therefore, at the prosperity section of the ETM, the sliders for the heating demand are set on -0.4% per year, which is shown in Figure 50.

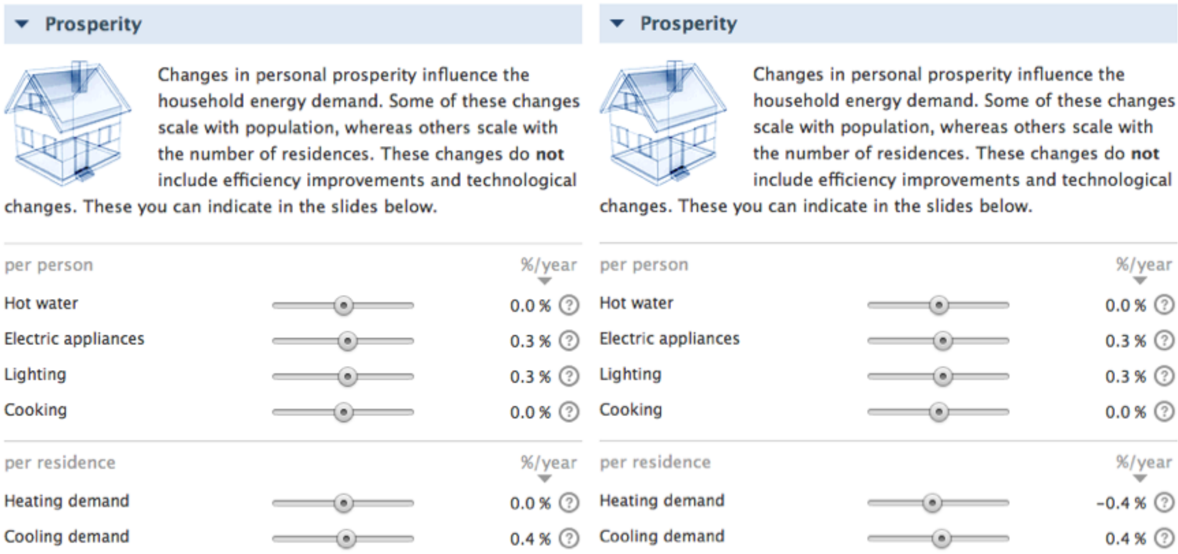


Figure 50. The settings of the ETM for the heating demand of the scenarios with a connection to low temperature district heating.

Appendix E - Concepts for design web tool and their considerations

In this Appendix, the six main design concepts which were considered before the final version of the web tool was designed are shortly described. Each concept was designed in an attempt to meet one or more of the requirements but failed in meeting at least one of them. The design of each concept, however, provided input for the next one, and as a result of this process it was possible to reach a final design that fulfilled all requirements.

It must be noted that the first 5 concepts were designed before the selection of the alternatives was definitive, and thus they were not resembling the precise set of alternatives and attributes that was eventually chosen. These 5 previous concepts include 6 alternatives and the option to choose insulation or not, resulting in a total of 12 alternatives. Only, the last concept has taken into account the final 16 alternatives, which can be found in Chapter 9.

Concept 1 – Modular display of the alternatives

In the first concept – as well as the next three – only modifications to the main page were considered. A print screen of the concept is shown in Figure 51. The modifications are listed here:

1. Each respondent would be asked to choose an alternative for the use natural gas in the whole neighborhood. In the web tool of the TAA, the number of projects can vary, as long as the budget constraint is met. However, in this case, the different alternatives together need to provide 100% of the heat demand of the neighborhood. In order to make the web tool more realistic, the respondent would have the opportunity to combine building blocks of 25% of each of the considered alternatives. They could also select the opportunity to insulate their house up to 50% or 100%.
2. Additionally, to make it understandable, a table was added to the main page with an overview where the respondent could see directly what the impact of the selected alternatives would be. The table would automatically calculate the effects of each composition of alternatives on the attributes.

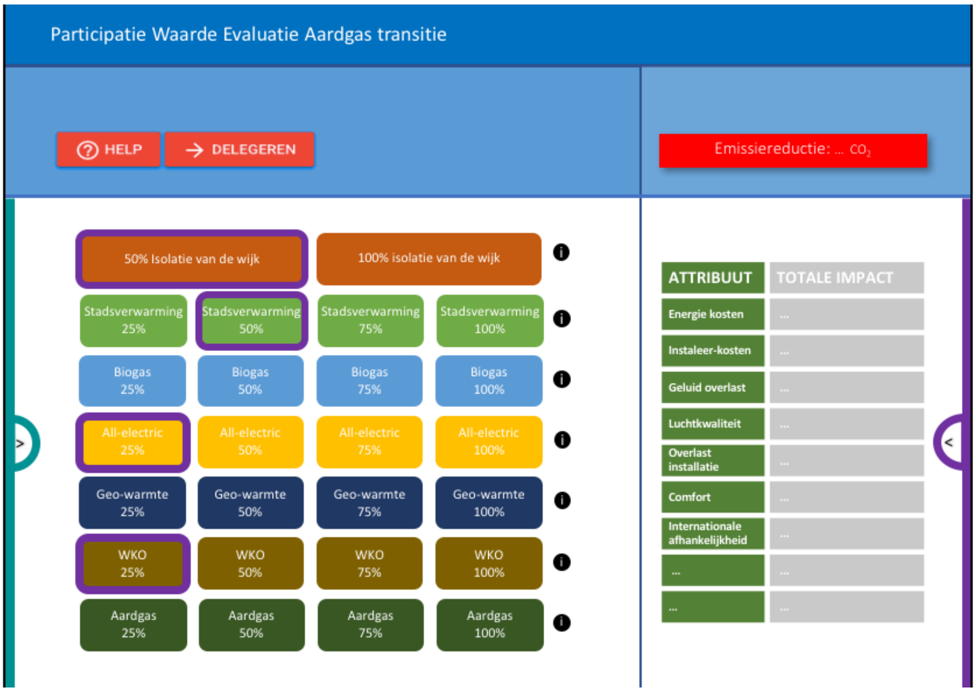


Figure 51. A print screen of Concept 1 – Modular display of all the alternatives.

3. Additionally, to make it understandable, a table was added to the main page with an overview where the respondent could see directly what the impact of the selected alternatives would be. The table would automatically calculate the effects of each composition of alternatives on the attributes.
4. A bar was also added (Figure 52) to show whether the selected combination would meet the constraint of reaching 100% renewable energy sources by 2045.

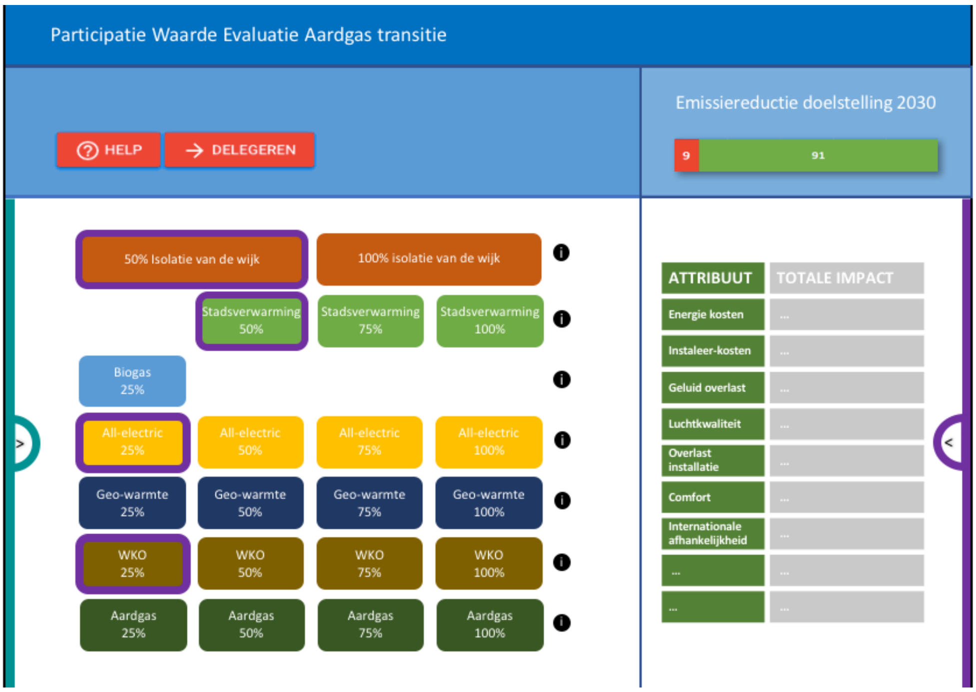


Figure 52. A print screen of Concept 1 – Modular display of all the desirable the alternatives.

5. It was also considered to remove those alternatives that were not desirable. For example, as discussed in Chapter 9, the option to have biogas as the only energy source (100% biogas) would not be desirable, since this solution would not be applicable on a larger scale due to the scarcity of biogas.

For the next concept, however, the idea of removing the undesirable alternatives was dismissed. The web tool is indeed required to provide the residents of Hengstdal with a complete overview of the alternatives so that they can decide whether a specific alternative is desirable or not **(constraint 1).**

Concept 2 – Static pie chart that displays alternatives

In the second concept, the building-blocks were interchanged with a pie chart. A print screen of the concept is shown in

Figure 53. The modifications are listed here:

1. In order to make it clearer that the different alternatives together need to provide 100% of the heat demand of the neighborhood, they were displayed as a pie chart.

Figure 53. A print screen of Concept 2 – Pie chart display of all the alternatives, without and with an alternative selected.

The respondent can select one of the alternatives on the left, and the selection would automatically fill 25% of the pie chart, as shown in the upper right corner of

2. Figure 53. The respondents could also select the same alternative again, which would automatically fill another 25% of the pie chart, shown in the lower right corner Figure 53.

For the next concept, it was decided to remove the constraint of choosing multiples of 25% of the alternatives, to make it more realistic **(constraint 2).**

Concept 3 – Dynamic pie chart that displays alternatives

In the third concept, respondents were given the opportunity to decide themselves the distribution of the selected alternatives. Therefore, the constraint of choosing only a maximum of four alternatives (representing 25% of the total each) was dropped; in this concept, respondents would be free to choose up to six different alternatives. A print screen of the concept is shown in Figure 54. The modifications are listed here:

1. The respondents were given the opportunity to decide themselves what distribution of the alternatives would be preferable.
2. The first way to modify the distribution is by typing in the values, which is shown in Figure 54 on the top right corner.
3. The second way to modify the distribution is to drag the edge of the slice to the desired amount, which is shown in Figure 54 in the right corner below.

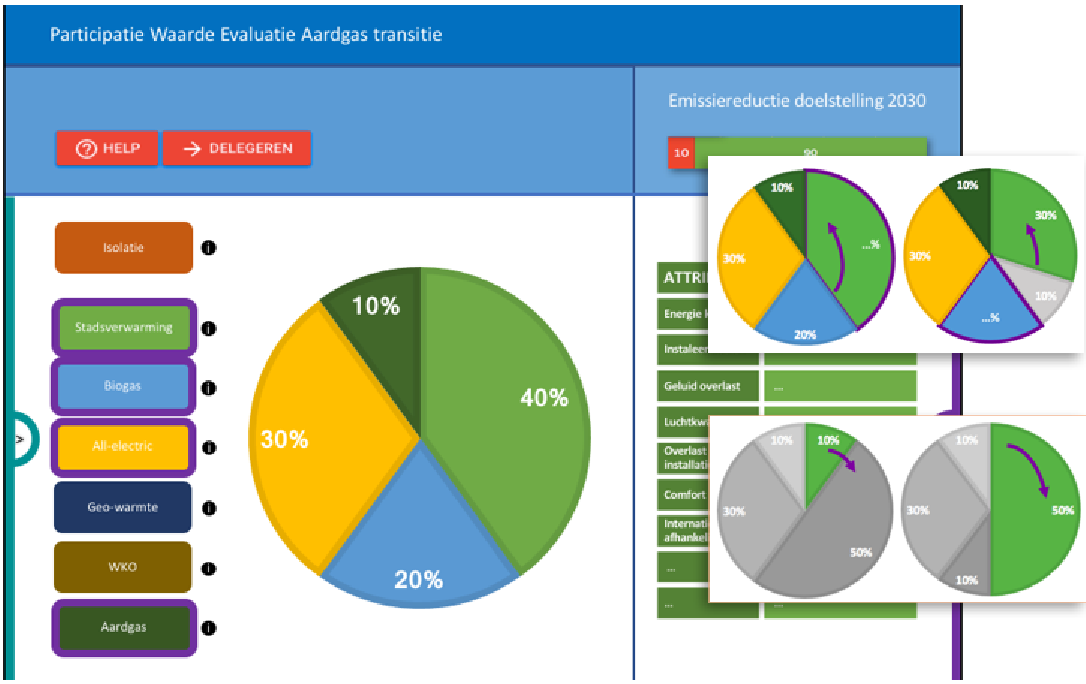


Figure 54. A print screen of Concept 3 – Dynamic pie chart display the selection of four alternatives. And on the top right corner the way to modify it by hand, or to modify it by dragging the edge of the slice, which is shown in the right corner below.

However, the idea of the removing the constraint of the maximum share of 25% per alternative was dismissed, because it would have been too complicated for the respondents to keep a clear oversight of the effects of each possible set of alternatives **(constraint 3).**

In next concept, it was decided to incorporate the effects of the insulation on the final energy consumption. In the first three concept, the final energy consumption was fixed – thus the size of the pie chart was fixed as well. This constraint was removed in the next concept.

Concept 4 – Dynamic pie chart that displays alternatives and energy consumption

In fourth concept, the effects of insulation on the total energy consumption of the neighborhood are showed. The decreased (or increased) consumption was showed by a smaller (or larger) pie chart. A print screen of the concept is shown in Figure 55. The modifications are listed here:

1. The surface of the pie chart decreases relative to the energy consumption. In this way respondents can immediately see what the effects of insulation are.

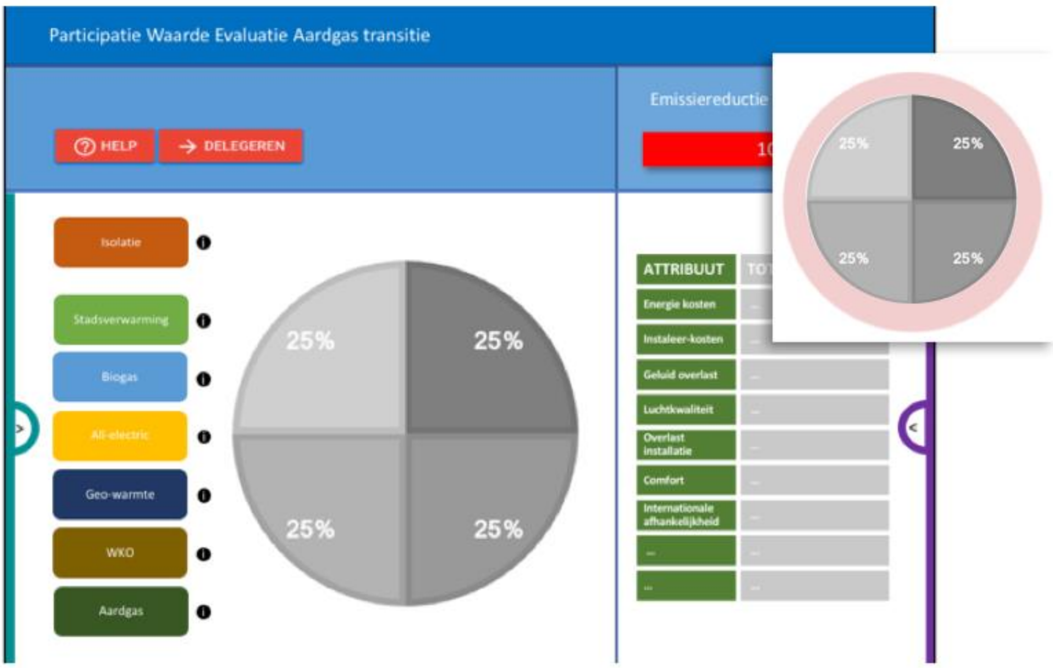


Figure 55. A print screen of Concept 4 – Dynamic pie chart that displays alternatives and effect of insulation on the total energy consumption of the neighborhood. The top right corner shows the pie chart after selecting the option to insulate: the surface of the pie chart decreases relative to the energy consumption.

For the next concept, the idea was to ask background questions – based on the follow-up questions introduced in step 3 of the PVE method – before the main page of the web tool, in order to make a more realistic calculation of the effects of each alternative on the constraint and attributes **(constraint 2)**.

Concept 5 – Questions asked beforehand

In the fifth concept, background questions were asked before the main page of the web tool. A print screen of the concept is shown in Figure 56. The modifications are listed here:

1. An extra page with questions is added prior to the main page. Questions are asked in order to have more input data for the calculations of the effects of each alternative on the constraint and attributes.
2. An extra column was added to the table on the main page. Here, the respondent could see the effects of the alternatives on the constraint and attributes specifically for his or her house, based on the answers of the questions asked beforehand. The other column would show the effects for the neighborhood as a whole. In this way, the resident could see the effects of his choices at both individual level and for the whole neighborhood.

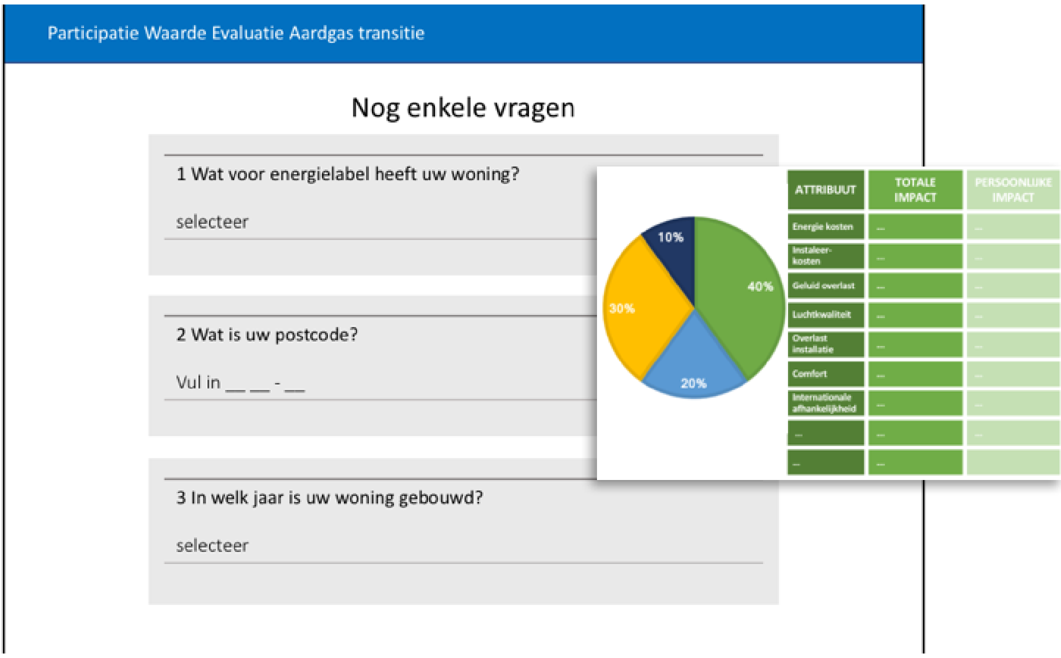


Figure 56. A print screen of concept 5 – Questions asked beforehand. These questions are asked in order to make a more realistic calculation of the effects of each alternative on the constraint and attributes. On the right, there is also a print screen of part of the main page, where the table is shown with a column for the effects for the whole neighborhood and for the respondent.

However, this idea was dismissed as well, because it would make it too complicated for the respondents to have a clear oversight of the effects of each alternative. Keeping track of the effects at both individual and neighborhood level was thought be confusing for most respondents **(constraint 3**).

For the next concept, the number of available alternatives was increased to 16 to include the option of choosing the type of energy source for each alternative **(constraint 1 and 2).**

Concept 6 – Alternatives with fossil or renewable energy sources

In the sixth and last concept, all the sixteen options – introduced in Chapter 9 – were incorporated in the design of the concept. A print screen of the concept is shown in Figure 57. The modifications are listed here:

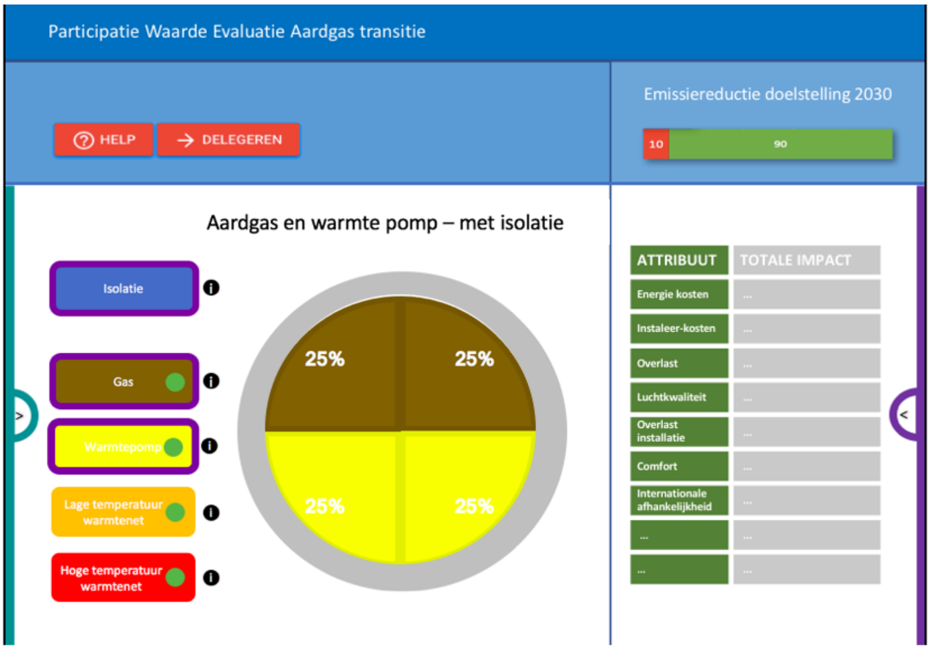


Figure 57. A print screen of Concept 6 – Alternatives with fossil or renewable energy sources.

1. Respondents have the option to choose between the four types of networks with their according installations.
2. Respondents can also select the option to insulate the house. The size of the pie chart decreases accordingly when this option is selected, to resemble the lower energy consumption.
3. Respondents have the option to select whether they want to use a renewable energy source for the selected alternative. They can select the specific renewable energy source by clicking on the green button on each alternative.
4. A title is added to the pie chat, which shows all the chosen alternatives together. For example, if you choose natural gas, a heat pump and insulation, without selecting the option for renewable energy sources, the title will turn to: Natural gas and heat pump with insulation.

For the final concept, the idea of adding a button that indicates whether the source of the alternative is green was dismissed, since it would have been too expensive and not within the budget set by the municipality for developing the web tool **(constraint 4).**

Lastly, it was also decided to dismiss the option to choose several alternatives at once. If the respondents have the option to choose a different alternative – out of the 16 alternatives – for each of the 25% of the neighborhood, this would mean that 16^4 = 65,536 different combinations of alternatives can be composed. There are 8 attributes, which would mean that 524,288 calculations are required. This is outside of the scope of this thesis, and therefore – even though it would be a better resemblance of reality – it was decided to make it simpler: respondents can only choose one alternative for their neighborhood at the time. The final design of the web tool will be discussed in the next paragraph.