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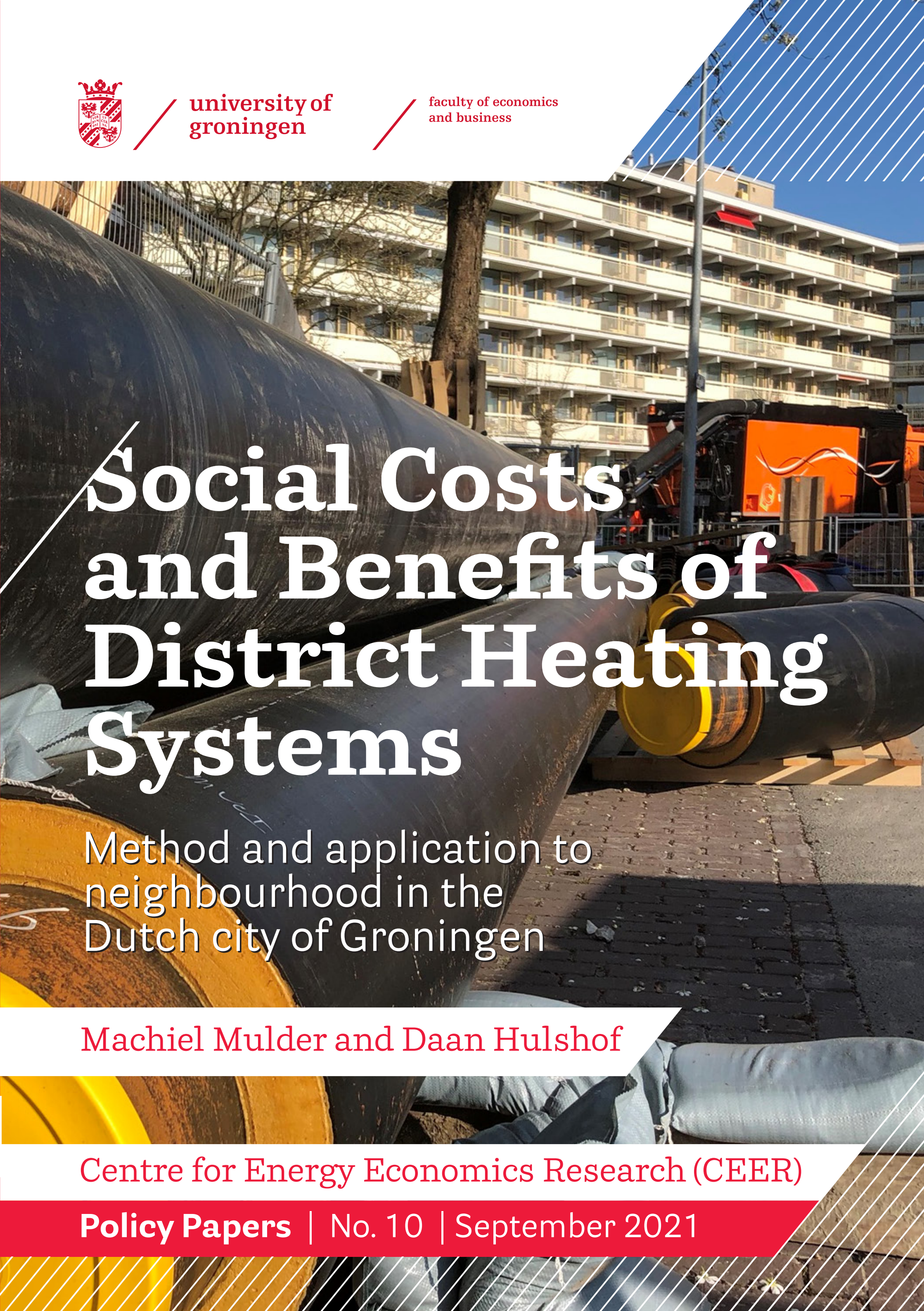

Social Costs and Benefits of District Heating Systems

Method and application to neighbourhood in the Dutch city of Groningen

Machiel Mulder and Daan Hulshof

Centre for Energy Economics Research (CEER)

Policy Papers | No. 10 | September 2021

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Social Costs and Benefits of District Heat systems; Method and application to neighbourhood in the Dutch city of Groningen
Centre for Energy Economics Research, CEER Policy Papers 10 – University of Groningen, The Netherlands – September 2021

Keywords:
Social Cost-Benefit Analysis, District heating, Energy Transition in the Built Environment

The research for this policy paper has been conducted with financial support from the Municipality of Groningen. The full responsibility for the content of this paper lies solely with the authors. This paper does not necessarily reflect the opinion of the Municipality of Groningen.

ISBN: 978-94-034-2933-5 (print)
ISBN: 978-94-034-2934-2 (pdf)

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1. De methode van maatschappelijke kosten-baten analyse (MKBA) blijkt een krachtig instrument te zijn om een systematisch overzicht te verwerven van de diverse factoren die de welvaartseffecten bepalen van bepaalde beleidsmaatregelen, zoals de introductie van een lokaal warmtenetwerk. Hoewel niet altijd alle effecten in geld kunnen worden uitgedrukt, stelt het instrument MKBA ons toch in staat om te bepalen hoeveel zo'n effect waard zou moeten zijn om een project maatschappelijk rendabel te maken. Deze zogenaamde break-even waardes kunnen gebruikt worden als referentiebedrag in politieke discussies over de wenselijkheid van een project.
2. Wanneer alle factoren in de beschouwing worden betrokken, dan blijkt dat het aanleggen van een lokaal warmtenetwerk in het Noordwesten van de gemeente Groningen maatschappelijk een gunstige investering is wanneer een hoge waarde wordt toegekend aan externe (ongeprijsde) factoren. Wanneer bijvoorbeeld de waarde van het reduceren van CO_2 emissies wordt gezet op minimaal 500 euro/ton, dan kan het warmtenetwerk per saldo een positief welvaartseffect hebben. Het welvaartseffect is eveneens positief wanneer het maatschappelijk belang van vermindering van het verbruik van aardgas (nog los van andere effecten) wordt gewaardeerd op minimaal 0,80 euro/m^3 gas. Het is dan wel van belang dat de warmte op 70 graden Celsius bij woningen wordt afgeleverd en dat de stroom op (grotendeels) hernieuwbare manier wordt geproduceerd.
3. De benchmark voor het beoordelen van deze break-even waardes kan worden afgeleid van de kosten die moeten worden gemaakt om de overheidsdoelstelling op een andere manier te halen. Wanneer de gemeente het aardgasverbruik bij de verwarming van huizen wil terugbrengen, dan omvatten deze alternatieve manieren onder andere

het gebruik van groene gassen (zoals waterstof) of volledige elektrificatie van de verwarming door het gebruik van warmtepompen in woningen. Het aanleggen van een warmtenetwerk is maatschappelijk gezien dus doelmatig wanneer de kosten (d.w.z. het negatieve saldo van de MKBA) kleiner zijn dan de kosten van deze alternatieve opties voor verduurzaming. Door CPB en PBL is bijvoorbeeld eerder berekend dat de maatschappelijke kosten voor het bereiken van de 2-graden klimaatdoelstelling in de orde van grootte liggen van 100-1000 euro/ton CO_2 (afhankelijk van scenario's). De door ons geschatte maatschappelijke kosten van het warmtesysteem liggen dus in deze range.

4. Uit de MKBA volgt verder dat de welvaartsbijdrage van de indirecte economische baten, zoals de voordelen van het gezamenlijk aanleggen van infrastructuren (zoals warmtenetwerk met elektriciteits- of telecomnetwerk) ten opzichte van de totale kosten niet zo groot is. Daartegenover staat dat de kosten van vergroting van het elektriciteitsnetwerk aanzienlijk kunnen zijn wanneer de stroomvraag van huishoudens sterk toeneemt.
5. Het optimale ontwerp van het warmtesysteem hangt met name af van de mate waarin de aan te sluiten woningen geïsoleerd zijn, hoe hoog de stroomprijs in de toekomst zal zijn, hoe groen die stroom wordt opgewerkt, en hoe groot de afstand is met bronnen van restwarmte.
6. Warmtesystemen die warmte van onder de 70 graden Celsius aanbieden, zijn relatief duur wanneer in woningen daarvoor grote aanpassingen moeten worden gepleegd in isolatie en warmteafgifteapparatuur. In het algemeen geldt dat de minst dure optie een warmtesysteem is waarbij de warmte met een temperatuur van 70 graden wordt afgeleverd bij de woningen omdat dan zulke aanpassingen niet nodig zijn. Dit geldt overigens minder wanneer de aan te sluiten woningen relatief nieuw en goed geïsoleerd zijn.

7. Warmtesystemen die warmte van onder de 70 graden Celsius gebruiken en op een hogere temperatuur afleveren, hebben een relatief grote behoefte aan elektriciteit vanwege de benodigde inzet van warmtepompen. Dit maakt dat de welvaartseffecten in zulke systemen sterk samenhangen met de kosten van elektriciteit, de kosten van aanpassingen van het elektriciteitsnetwerk, en de wijze waarop de elektriciteit wordt opgewekt. In een scenario met oplopende elektriciteitsprijzen, zullen zulke warmtesystemen met een grote rol voor warmtepompen moeilijk rendabel zijn. Bovendien zullen de milieubaten vrij beperkt zijn wanneer de elektriciteit grotendeels wordt opgewerkt met fossiele energie (d.w.z. kolen- of gascentrales).
8. Wanneer in een warmtesysteem warmte van medium of hoge temperatuur (d.w.z. 50 of 70 graden Celsius) wordt gebruikt, waarvoor een transportinfrastructuur moet worden aangelegd, dan hangen de welvaartseffecten sterk af van de afstand die overbrugd moet worden tussen de warmtebron en het warmteverbruik. Hoe groter die afstand, hoe hoger de kosten van het warmtetransport.
9. De uitkomsten van de MKBA zijn uiteraard gevoelig voor de gemaakte veronderstellingen. De welvaartseffecten zullen positiever (of minder negatief) zijn, wanneer een hogere gasprijs wordt verondersteld, een lagere elektriciteitsprijs, een kortere afstand tussen de locatie van de warmtebron en het distributienetwerk, een langere doorlooptijd van het ontwikkeltraject en een lagere disconteringsvoet, en v.v.
10. De welvaartseffecten van een lokaal warmtenetwerk worden positief beïnvloed wanneer sprake is van een streng (inter)nationaal klimaatbeleid, althans wanneer dit resulteert in een hoog aandeel van hernieuwbare stroomopwekking en hoge belastingen op het gebruik van aardgas. De ontwikkelaar van een warmtesysteem waarvoor veel elektriciteit nodig is, kan zelf ook bijdragen aan de vergroting van het

aandeel hernieuwbare opwekking door te investeren in een zonne- of windpark (al dan niet direct gekoppeld aan het warmtenetwerk), door het afsluiten van contracten met nieuwe hernieuwbare-stroomprojecten elders (via *Purchasing Power Agreements)*, of door de koop van groencertificaten waarmee investeringen in zulke projecten rendabeler worden. Nationale overheden kunnen de business case van warmtenetwerken bevorderen door het aanpassen van de energiebelastingen, dat wil zeggen hogere tarieven op het verbruik van aardgas en lagere op het verbruik van elektriciteit.

11. Wanneer een lokaal warmtenetwerk (op die manier) een positieve business case heeft, dan is de vervolgvraag hoe marktpartijen kunnen bijdragen aan de realisatie daarvan. Vanwege onzekerheden over de ontwikkeling van de vraag naar warmte tijdens de uitrol van een warmtesysteem, ligt het niet meteen voor de hand meerdere, concurrerende producenten er bij te betrekken. Geleidelijk aan echter kunnen mogelijk wel meerdere producenten en leveranciers toetreden, wat kan leiden tot concurrentie en daardoor lagere kosten bij de warmteproductie (bijv. door een efficiënter gebruik van elektriciteit) en warmtelevering.

12. Een aldus ontstane (lokale) markt voor warmte zal worden versterkt wanneer sprake is van een onafhankelijke beheerder van de infrastructuur voor transport en distributie. Deze beheerder kan naast het technische beheer, ook de markt faciliteren door andere partijen toegang te geven en de marktplaatsen te organiseren. Aangezien de kosten van de (monopolistische) beheerder van de infrastructuur een groot onderdeel uitmaken van de totale warmtekosten, is het belangrijk dat deze beheerder onderworpen is aan regulering die hem prikkelt om doelmatig te werken, zelfs wanneer de beheerder in publieke handen zou zijn.

Conclusions

1. The method of social cost-benefit analysis (CBA) appears to be a powerful tool to obtain a systematic overview over the various factors that affect the overall welfare effects of policy interventions such as the introduction of a district-heating system. Although not always all effects can be expressed in monetary terms, the tool of CBA enables one to determine the required break-even values for such effects. These break-even values can be used as reference values in political discussions on the desirability of a project.
2. Taking all factors into account, we conclude that a district-heating system in the North-western part of the city of Groningen is beneficial from a social welfare point of view when a high value is attached to external factors. When the value of the reduction in emissions of CO_2 is at least valued at about 500 euro/ton, the overall welfare effect is positive. The same holds when the societal value of reducing gas consumption (on top of any other effect) is at least valued at 0.80 euro/m^3 of gas. These results of the CBA only occur when the heat is delivered at the houses at 70 degrees Celsius and the electricity is mainly generated in a renewable way.
3. Given the policy objective of fully replacing natural gas for heating of residential buildings, the benchmark for these break-even values is given by the costs of alternatives (such as using renewable gases (such as hydrogen) or by fully electrification of houses) to realize that objective. This means, that the policy of implementing a district-heating system is socially efficient when the costs of other options (i.e. the negative net welfare effect) to realize that objective exceed these break-even values. By the Dutch research institutes CPB and PBL, it was earlier concluded that the societal costs of reaching the 2-degrees climate policy target are

in the range of 100-1000 euro/ton CO2 (depending on scenarios). Hence, our estimate for the social costs of district-heat systems are within this range.

4. From the CBA, it further appears that the contribution of indirect benefits to the overall welfare effect, such as potential efficiencies through joint implementation of infrastructures (such as heat networks with electricity or telecom networks), is fairly small. It also appears that the costs of electricity grid extension can be significant when the electricity demand for heat pumps increases strongly.
5. We find that the optimal design of a district-heating system basically depends on the characteristics of the houses, in particular their degree of insulation, the future electricity price, the way electricity is generated (fossil-fuel based or renewable), and the distance between the source of heat and its destination, i.e. the location of the houses to be connected.
6. A district-heating system that supplies low- or medium-temperature heat (i.e. below 70 degrees Celsius) to households is relatively costly because of the required investments in insulation and heat distributors in residential buildings. Generally, one can conclude that the least costly option for district-heat systems is to deliver heat at the current temperature of 70 degrees Celsius as then such investments are not required. This conclusion does of course not hold when the houses are relatively new and well insulated.
7. District-heating systems that use a low- or medium-temperature heat source require significant amounts of electricity, which make that the welfare effects of such a design strongly depend on the costs of electricity, the costs of electricity-grid extension as well as the way electricity is generated. This implies, amongst others, that in a scenario with increasing electricity prices, such heating systems can hardly be profitable. Moreover, the environmental benefits will be modest when

the electricity is mostly generated through fossil energy (i.e. coal or gas-fired power plants).

8. When district-heating systems use heat of higher temperature (e.g. 50 or 70 degrees Celsius), a transport infrastructure has to be developed. As a result, the welfare effects of such a variant strongly depends on the distance between source and destination. The higher this distance, the higher the costs of heat transport.
9. The results of the cost-benefit analysis are, of course, sensitive to the assumptions made. The welfare effects are positively affected when the wholesale price of gas is higher, the wholesale price of electricity is lower, the distance between a medium heat source and the distribution grid is smaller, the project is partly shifted to the future, or a lower discount rate is used, and the other way around.
10. The welfare effects of district-heating systems are also positively affected by the presence of fierce (inter)national climate policy when this results in higher shares of renewable electricity and higher taxes on the use of natural gas. The developer of a district-heat system that uses a lot of electricity, can also itself contribute to increasing the share of renewable electricity in a system by investing in a solar-panel or wind turbine park (not necessarily directly connected to the heat system), concluding contracts with renewable-electricity developers (through so-called Purchasing Power Agreements) of by buying green-electricity certificates. In addition, national governments can facilitate the economic business cases of district-heating systems by simply adapting the tax tariffs on gas (i.e. higher) and electricity (i.e. lower).
11. When a district-heating system is (made) profitably from a business perspective (through for instance redesigning energy tax tariffs), the next question is to what extern market parties can contribute. Because of uncertainties regarding the future demand during the development of a

district-heat system, extending the number of producing firms may be problematic. Later on, however, facilitating the entrance of multiple players in the production and supply of heat may result in competitive pressure to reduce the costs of heat production (e.g. through more efficient use of electricity) and heat supply.

12. This process of creating a district-heating market can be fostered by creating an independent heat-transport operator, who is only responsible for developing and operating the infrastructure, and facilitating market processes. As the costs of the (monopolistic) transportation infrastructure constitute a major part of the total costs of providing heat to end-users, the operator of the infrastructure should receive (regulatory) incentives to operate efficiently, even if this operator is fully publicly owned.

1. Introduction

1.1 Background and objective

As part of the (inter)national climate policies, Dutch municipalities face the challenge to realise a transition in the heating of residential buildings. This transition basically means that the use of fossil energy (i.e. natural gas) for heating has to be replaced by renewable heat sources. One option to do this is to develop district heating systems which make use of residual or renewable heat sources. Up to now, there is only a limited experience with district-heating systems in the Netherlands, contrary to several other European countries. In particular in Scandinavian and Eastern European countries, district-heating systems have been introduced, where 40 to 60% of the households is connected to such a system, while for the Netherlands this share is about 5% (CBS).

District-heating systems have hardly been promoted by Dutch policy makers, which is reflected by the presence of a limited number of policy instruments aimed at the heating sector (CE Delft, 2021). Relatedly, there are relatively low levels of public support and participation for district-heating systems in the Netherlands (PAW, 2021). Furthermore, end-user prices for heat from collective heating systems in the Netherlands are relatively high in comparison with the neighbouring countries Germany, Denmark and the other Nordic countries (Huygen et al., 2021). At the same time, the experiences in the other countries illustrate that widespread development of district-heating systems requires significant investments in infrastructure.

It is clear that district-heating systems can be promoted by providing subsidies to the investors or end-users (as is suggested by e.g. IBO, 2021), but this does not necessarily imply that developing such systems are beneficial from a social welfare point of view. In order to determine the net benefits for society, all societal costs and benefits have to be taken into account. Such an analysis can be done through a so-called social cost-benefit analysis (CBA) (see e.g Mulder, 2020). In this method, which is based on welfare economics, not only effects (costs and benefits) which occur on markets and, hence, are priced, can be included, but also non-market (i.e. non-priced) effects, like environmental effects. In addition, a CBA also enables policy makers to determine the critical monetary value (i.e. break-even value) of a particular non-market effect to obtain a positive business case from a social-welfare point of view. As an example, suppose the overall welfare effect of a district-heating project is negative, but the project does reduce the local use of natural gas which may have a social value in itself (on top of the savings on gas consumption). Calculating the break-even value of this effect may facilitate the political discussion on the social desirability of the project.

Although some examples of CBA of district-heating systems exist (see e.g. Menkveld et al., 2016; Tieben et al, 2020), they are quite scarce up to now. The objective of this policy paper is therefore to show how a social cost-benefit analysis can be conducted for district-heating systems, which may help policy makers in their discussion of the social desirability of this policy option to reach their climate-policy objective.

1.2 Research scope

This policy paper describes how the overall costs and benefits of a district-heating system can be calculated by applying this method to a neighbourhood in the city of Groningen. As the objective of this policy paper is to demonstrate the use of the CBA method to district-heat systems, the focus is on the method and the way of (economic) reasoning. Although we try to make reasonable assumptions regarding the various aspects of the application, we are aware of the fact that some of these assumptions may be too simplistic and require further research.[1]

The municipality of Groningen has the ambition, just as many other Dutch municipalities, to realize a transition in the local heat supply towards renewable energy sources. From an explorative analysis, it already appears that this municipality has the potential to utilize various sources of renewable heat, in particular large scale geothermal and low temperature residual heat (Guidehouse, 2020). They conclude that the challenge for developing a district-heating system is not related to the availability of heat sources, as they seem to be relatively abundant, but to the development of the transport infrastructure. In this report, therefore, we assume that the required heat sources are present, and that the key question refers to the welfare effects of alternative designs of the heat system.

In order to answer that question, we develop and apply the CBA method. Using that method, we explore the welfare effects of alternative district-heating systems with varying design choices that can be influenced (so-called policy variants), under varying external circumstances that impact the results but cannot be influenced (so-called scenarios). The key design choices that define a policy variant and which are included in the model are the following: heat source (where options depend on the availability of sources in practice), source temperature (which is strongly linked to the heat source), distance between the heat source and the distribution network, delivery temperature, the project's starting year, the duration of the construction of the project and the lifetime of the system.[2] Scenario factors that impact the welfare effects of

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[1] The CBA model is operationalized in Excel, which is available to those who are interested to conduct the CBA themselves by using different assumptions or applying it to another region.

[2] Although the heat-pricing policy can be a component of government heat policy as well, it does in itself not affect the overall welfare effects, as it only affects the distribution of costs and benefits within society (ignoring behavioral responses). Therefore, in this report we assume that all costs are passed on to the end-users. In the

a policy variant include (future) energy prices, taxes and the national electricity mix.

Given a policy variant and a scenario, the CBA model quantifies i) the economic effects of households, the heat system supply chain (consisting of producer, transport and system operator, as well as supplier), and external sectors (such as gas producers and electricity grid operator), ii) external effects (e.g. CO_2-emission reductions), and iii) government (including taxes and subsidies). Based on these effects, the overall welfare effects can be calculated.

When a CBA results in a positive outcome for social welfare, the next step in the policy discussion is how such a project can be realised. This topic refers to the organisation of the industry and the role of market parties and governments. In this policy paper, we will only briefly touch on this issue.

1.3 Outline of this policy paper

First, the method of cost-benefit analysis and how it can be applied to district-heating systems is briefly described in Chapter 2. Chapter 3 and 4 discuss the definition of the policy variants and scenarios, respectively. In the Chapters 5 until and including 9, the economic effects for the various groups are discussed: households, heat system (including producer, transport operator, and supplier), related economic actors (in particular electricity grid operator and gas sector), external effects, and the government. The overall welfare effects are presented in Chapter 10, which also includes a number of sensitivity analyses as well as the analysis of a number of break-even values. The conclusions are presented (in Dutch and English) at the beginning of this Policy Paper.

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concluding section, however, we will briefly discuss the impact of pricing policy to facilitate investments in district-heating systems.

2. Social cost-benefit analysis of district-heating systems

2.1 Introduction

Social cost-benefit analysis (CBA) is a method to analyse the overall economic effects of particular interventions in economic systems. In Section 2.2, we briefly describe this method. In the next section, we show how the CBA can be used to analyse the economic effects of policy measures directed at the implementation of district-heat systems.

2.2 Welfare-economic framework

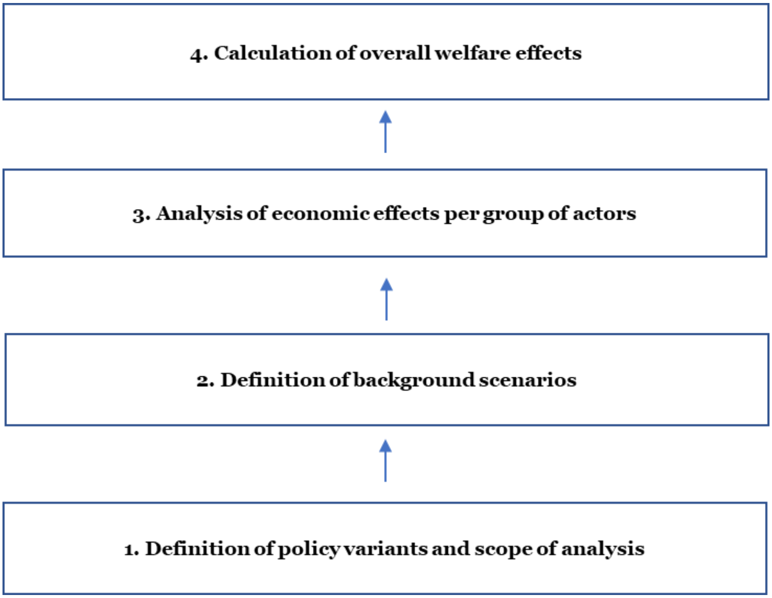
The welfare-economic framework for analysing costs and benefits of a particular (policy) intervention in the economy (such as building a district-heating system) is based on the microeconomic theory which states that (in principle) economic agents want to maximize their own interests (which is called utility for consumers and profits for firms). These interests not only include financial variables, but everything that is relevant from the perspective of individual economic agents (e.g. consumers and producers, but also organisations). In order to maximize their objectives, agents have to make choices regarding the usage of their resources (e.g. time, effort, capital). The choices may also refer to the exchange of commodities with other agents. This exchange is typically done on market places with many (or at least several) buyers and sellers, but it can also be done with one central agent as supplier. This exchange of commodities most of the time results in prices (in the case of market places), unless they are based on tariffs set by a single supplier (in the latter case). Anyway, these prices (or tariffs) reflect the marginal costs or revenues of the decisions considered by the agents (i.e. for buyers and suppliers, respectively). Hence, in order to assess the overall welfare effects of a particular decision (such as regarding a district-heating system), one should analyse how such a decision affects the interaction between the economic agents through markets, not only directly, but also through the markets of intermediate products. The former are called direct effects and the latter indirect effects.

In some cases, however, there is no explicit exchange of resources between agents, although their decisions do affect the availability of resources or, more generally, affect the so-called utility of (other) agents. In such cases, there are no (market) prices or tariffs which can be used to determine the costs of a change in the availability due to a particular choice. An example of this is the impact of the use of fossil energy on local air quality, which may be reduced by the introduction of a district-heating system. These unpriced factors are called external effects. The challenge, of course, is to find monetary values for those unpriced effects. This can be done through various methods, such as choice experiments (see Mulder, 2020). In this report, we just use estimates from external sources, while we also calculate the so-called break-even values for a number of external effects. By including all these (direct, indirect and external) effects, one can determine the overall economic effects of a particular intervention.

The steps to be set in a CBA can be distinguished in four categories (see Figure 2.1). The first step in conducting a CBA is determining the precise characteristics of the policy intervention and the scope of the analysis. Questions to be answered here are: what type of measure(s) (i.e. interventions in the economy) will be taken, how will they affect economic agents, and what should be the scope of analysis? The scope in particular refers to the geographical area for which the economic consequences have to be analysed.

The second step consists of determining the background scenarios, as the consequences of any policy interventions always depend on other (external) factors. When both the policy interventions and the background scenarios have been defined, then the economic effects for the various groups of economic actors can be determined. Based on the resulting effects per group, the consequences for the overall welfare can be determined.

Figure 2.1 Steps in a social-cost-benefit analysis



2.3 Framework of analysis for district-heating systems

Applying the above general framework of a CBA to the policy domain of district-heat systems, we obtain the framework depicted by Figure 2.2. In the first step, one has to determine the policy variants which means that the precise characteristics of the district-heat system have to be determined, in comparison to the situation in which no specific measures would be taken.[3] What will be the new heat sources and the source temperature, what kind of transportation and/distribution infrastructure has to be developed and what will be the delivery temperature in the premises of households? The answers to these questions also give information to what extent and where heat pumps are required to transfer the source heat to the temperature required by the households and/or to control for heat losses during transportation and/or distribution.

In this step also the scope of the analysis has to be determined. Questions to be answered include: for which geographical area should the economic effects be included and for which future period?

In the second step, one has to determine the scenarios regarding the external factors. In particular, assumptions have to made regarding the market prices of electricity, natural gas and carbon allowances. In addition, assumptions have to be formulated regarding governmental taxes on electricity and gas, as these taxes affect the end-user energy prices and, hence, the business case of district-heating systems. It may also be relevant to formulate assumptions regarding the availability of subsidies for households or heat producers. In order to be able to estimate the environmental effects, one also has to make assumptions regarding the composition of the national electricity portfolio. Preferably, these assumptions are not just arbitrarily chosen numbers, but they are based on internally consistent story lines about external developments (see also Mulder, 2020).

In the third step, the consequences per group of actor are analysed. This can be done in various ways. When the CBA refers to a policy intervention on national scale, then this may affect market prices. As a result, in such a case,

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[3] The policy variants are analysed in comparison to the situation in which no specific policy measures are taken, but where autonomous changes may occur. This reference variant is called the ‘null alternative’ in the CBA method.

the relevant markets should be analysed in order to determine the impact of the policy intervention on market prices. When a CBA, however, only refers to a policy variant on a local scale, such as a district-heating system in a local community, then one may assume that the market prices remain unaffected. In the latter case, one may just work with exogenously given market prices (determined in the scenarios) and then calculate the consequences per group of actor. This approach is chosen in this report because of the limited economic magnitude of the district-heat projects. Hence, in the third step, we calculate the economic consequences per group of actor: households (to be distinguished in various types), heat producer(s), heat-system operator, heat supplier, other economic sectors (such as gas producers and electricity-grid operator), and public authorities. In addition, we distinguish the group of external (unpriced) effects.

In the final step, we calculate the overall effects, controlling for transfers between groups (such as subsidies and taxes from and to the governments, and payments within the heat-supply chain), which do not result in a net overall economic effect. Afterall, costs for a particular group (such as tax payments by households) may be benefits for another group (in this case the government), which means that on the aggregated (national) level, such costs and benefits are cancelled out. The overall welfare effects are calculated as the present value of all costs and benefit during the period of analysis.[4]

In this final step, we also determine the so-called break-even values for various external effects. This means that we determine what the monetary value of these effects should be in order to make the policy variants profitable from a social perspective.

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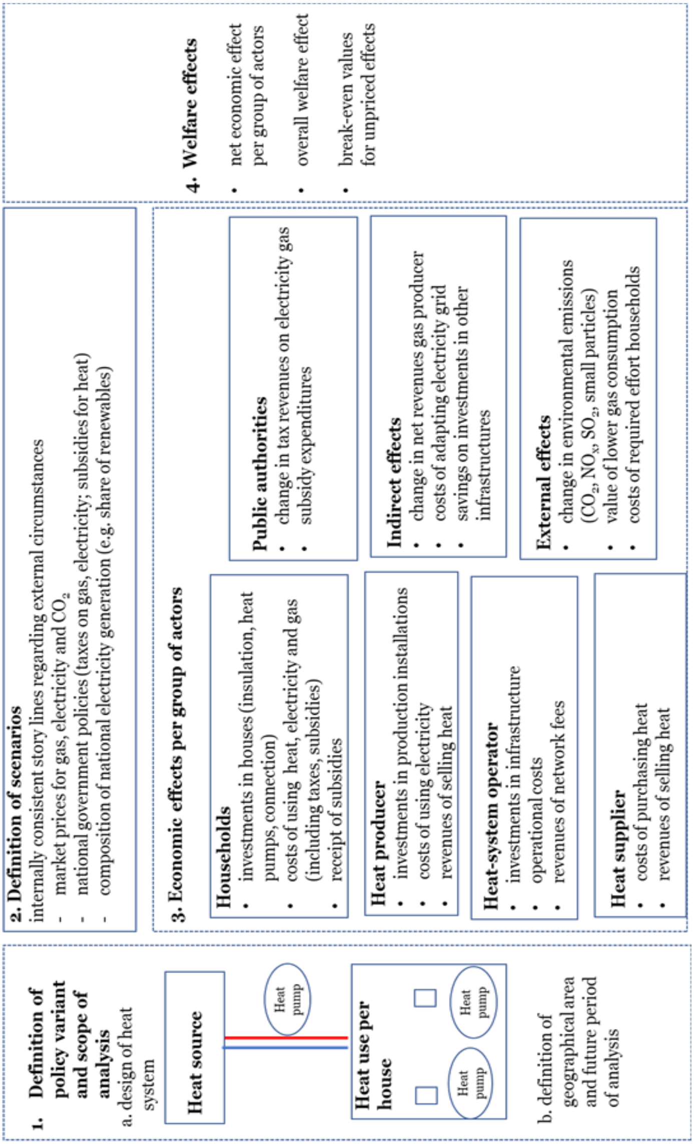
[4] By calculating the present value, one controls for differences in the timing of various types of costs and benefits. In Chapter 10, we will explore the sensitivity of the value of the discount rate.

Figure 2.2 Framework of CBA of district-heating system



3. Definition of policy variant and scope of analysis

3.1 Introduction

The first step in a CBA is to determine the precise characteristics of the intended policy decision and how the consequences of that decision have to be analysed. In this chapter, we describe how the district-heating systems can be defined, and what the various design options imply for the buildings. We also define the various variants.

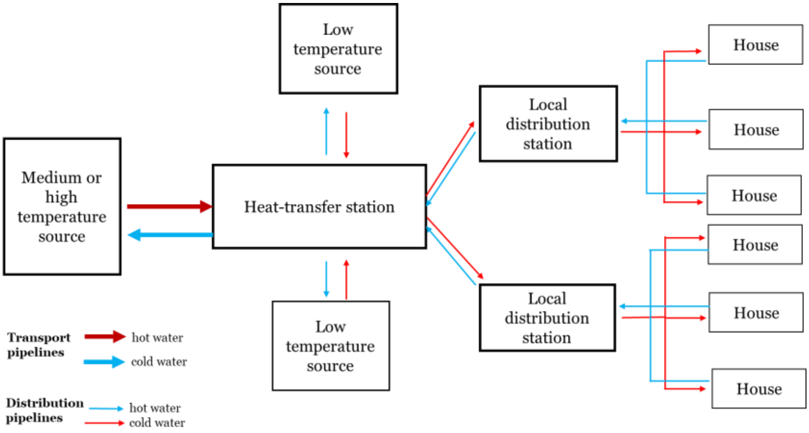
3.2 Characteristics of district-heating systems

District-heating systems are collective systems to satisfy the energy demand of individual end-users to heat their buildings (e.g. houses and offices). District-heating systems include one or multiple sources of heat (e.g. residual heat from an industrial site, geothermal heat) as well as a pipeline infrastructure to move heat from the source location to the end-users. In addition, a district-heating system consists of a heat-transfer station, where heat from the source is transferred to the distribution pipelines, and a number of local distribution stations, where the heat is transferred further in the direction of end-users. In many cases, this supply chain of district-heat systems is vertically organized, which means that one organisation is responsible for all the various activities (i.e. production, transport, distribution and supply). In some countries (cities), however, the various activities in the supply chain are conducted by different parties, although generally a vertically integrated organisation is the dominant form (PWC, 2015; Åberg et al., 2016). In the future, this may change into systems with independent infrastructure operators (see e.g. Van Benthem and Tieben, 2020).

Technically, heat systems function as follows. Heat is transported in pipelines filled with water. Water is heated at the source location (or hot water is directly extracted from e.g. the earth), and transported through pipelines to the location where the heat is demanded. The pipelines are duplicated, where in one of the pipelines hot water flows from the source to the demand location(s), and in the other pipeline the used, cooler water flows in the other direction, where it can be reheated at the source location or disposed.

The pipeline infrastructure in a district-heating system may contain both transportation and distribution pipelines. Transportation pipes serve to transport very large volumes of heat from, for instance, an industrial site with residual heat, to a heat-transfer station (see Figure 3.1). These stations form the starting point of the distribution grid that distributes heat to many different points in a residential neighbourhood where space heating is demanded. This means that transport pipelines may consist of just a few pipes, whereas the distribution pipelines consists of many, relatively smaller pipes.

Figure 3.1 Schematic overview of district-heating systems based on a high- or medium-temperature source or low-temperature sources



While every district-heating system requires a distribution grid, not every system requires transportation pipelines. Transportation pipelines are typically required when a high- or medium-temperature (above 50 degrees Celsius) heat source is located relatively far away (e.g. >10km) from the location where the heat is consumed. Given that low-temperature heat (below 50 degrees Celsius) sources are generally located in the proximity of consumption locations, transport pipelines are not necessary in these configurations.

In district-heating systems, the temperature of the heat source does not need to be equal to the temperature at which the heat is delivered to end-users through the distribution pipelines. When the latter temperature is higher than the former, an electrical central heat pump is required in order to upgrade the temperature of the water in the distribution pipes. In this case, the heat is supplied from two sources: the heat source itself and the electricity used by the heat pump.

In some cases, the temperature of the heat delivered to the houses is too low to heat the buildings sufficiently. The demand of households for space heating depends on the characteristics of their buildings, in particular the insulation properties. In case of district-heating systems with a low delivery temperature, the level of the heat demand has to be reduced. In addition, other measures on the building-level may be required for a well-functioning district-heating system. These measures include the installation of a heat pump for in-house heat production, low-temperature heat distributors (e.g. radiators) and an alternative appliance for cooking. Whether these measures are required depends primarily on the temperature at which the heat is delivered to buildings by the district heating system. When the delivery temperature is equal to the currently prevailing water temperature of heating systems in Dutch houses of about 70 degree Celsius, very few building measures are required, but when the temperature is lower, more adaptations are required.

3.3 Options for district-heating system in the CBA model

The CBA model which we have developed, enables the user to choose the characteristics of the district-heating system for which the cost-benefit analysis has to be done.[5] The choices which can be made refer to the temperature of the heat at the source as well as the temperature at which the water is delivered to the buildings, the type of heat source, the starting year of the construction, the expected duration of the construction project, and, in case of a medium or high-temperature source, the distance to the distribution grid. (see Table 3.1). These choices together form the so-called policy variant of the CBA.

Depending on the characteristics of the chosen district-heating system, the model automatically chooses the relevant infrastructure. This refers to the following aspects:

- Investments by the heat producer in equipment to produce and/or to transfer the heat to the transportation infrastructure. These investments depend on the type of heat source chosen.[6]
- Investments by the heat-system operator in the required infrastructure to move the heat from the source to end-users. This infrastructure always includes distribution and connection pipes, as well as local distribution stations. The infrastructure of the heat-system operator only includes transportation pipes in medium or high-temperature configurations (i.e. when the source temperature is at least 50 degrees Celsius). When the

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[5] See footnote 1.

[6] For instance, some sources require drilling a well (e.g. geothermal energy) whereas others require the installation of heat exchangers (e.g. residual heat from industry).

source temperature is below the delivery temperature, the heat-system operator invests in a centrally located heat pump in order to increase the heat at the heat-transfer station before it enters the distribution grid.

Table 3.1. Defining the policy variants: design options in the CBA model

Element	Options in model
Source temperature (degrees Celsius)	• 15 [very-low temperature] • 30 [low temperature] • 50 [medium temperature] • 70 [high temperature]
Heat source per source temperature	15 degrees: • Aqua thermal energy (AE) • Aquifer thermal energy storage (ATES) (heat-cold storage) • AE+ATES 30 degrees: • LT source 50 or 70 degrees: • Residual heat from industry • Residual heat from power generation • Geothermal energy • Bio-based CHP
Delivery temperature (degree Celsius)	• 30 • 50 • 70
Distance to distribution grid (in case of medium or high temperature source)	Choose number of kilometers
Lifetime of system	Choose number of years
Duration of construction (in years)	Choose number of years
Starting year of construction	Choose year

- In order to explicitly account for the costs of transportation, the model distinguishes between the role of the transport operator and the heat supplier. It is assumed that the latter purchases the heat from the heat producer and sells is to the households. The households are assumed to pay a fee to the transport operator to compensate for the costs of the transport infrastructure. The costs of energy losses due to transportation are assumed to be a part of the heat price, while the transport fee only refers to the costs of investing and operating the infrastructure.
- In addition, depending on the temperature of the delivered heat, the model automatically determines which adaptations are required on the building level and the associated impact on the demand for heat. These adaptations in particular refer to the insulation of houses, but may also extend to the installation of in-house heat pumps.

3.4 Defining the scope of analysis

Policy variants consist of a set of policy interventions which in particular affect a specific region (e.g. neighbourhood in a municipality), while the effects of these measures may spill over to a wider region. In addition to the instantaneous impact, the policy intervention may also have effects that materialize in the future. Defining the region where the measures will be implemented as well as the region and time period for which the consequences have to be assessed, results in the scope of the CBA.

For the region where the district-heating system is considered, it is important to consider the type of buildings that need heat. As heat consumption varies across buildings, the model differentiates between twelve types of residential buildings with distinct characteristics (see Table 3.2).[7]

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[7] Office buildings and industrial sites are not considered.

Table 3.2 Defining the regional scope

Element	Options in model
Type of buildings in region of analysis	• 12 types of buildings are distinguished
Regional scope of effects	• National

3.5 Application to city of Groningen

3.5.1 Defining scope of analysis

The municipality of Groningen considers to implement a district-heating system in the North-western part of the city, specifically in the neighbourhoods *Vinkhuizen-Noord & -Midden*, *Paddepoel-Noord & Midden*, and *Selwerd-West* (see Figure 3.2). This area includes 3200 residential buildings. Table 3.3 describes the characteristics of the various types of residential buildings in this region, including the so-called Dutch Energy Label. [8]

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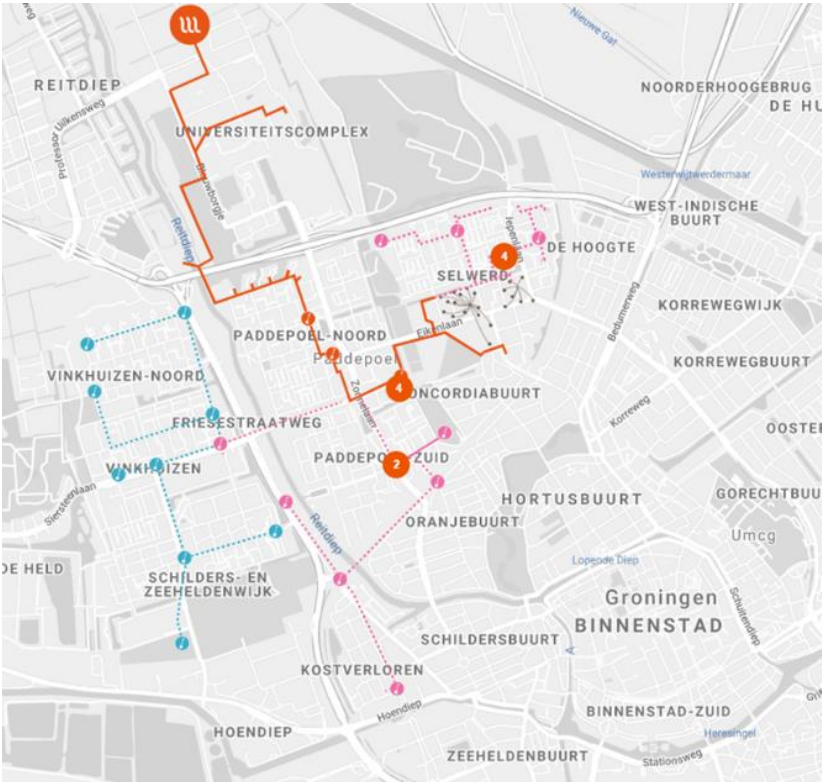
[8] Buildings in the Netherlands are classified on the basis of their energy efficiency and accordingly receive an energy label. The energy label runs from A (very efficient) to G (very inefficient).

Figure 3.2 Spatial design of the scheduled district-heating system in the North-western part of the city of Groningen



Note: Orange lines are realized pipelines, pink lines are to be constructed in 2021-2023 and blue lines are to be constructed in 2022-2025. Source: http://www.warmtestad.nl.

Table 3.3 Characteristics of residential buildings in region of analysis (Groningen North-West)

Residence type and building period	Number of buildings	Energy label	Gas consumption average per building (m3/year)
Detached (<1975)	12	F	2750
Detached (1975-1995)	0	E	2600
Detached (>1995)	0	B	2250
Semi-detached (<1975)	49	F	2225
Semi-detached (1975-1995)	0	E	1900
Semi-detached (>1995)	2	B	1650
Terrace (<1975)	848	F	1750
Terrace (1975-1995)	8	E	1500
Terrace (>1995)	76	B	1400
Flat (<1975)	1978	F	1250
Flat (1975-1995)	76	E	1050
Flat (>1995)	151	C	1000
Total	3200		

Note: Source for the number of buildings is Municipality of Groningen; The Energy labels are our own assumptions; Source for average gas consumption is PBL.

Based on this table and assuming that 5% of gas is consumed for cooking, we are able to estimate how much gas is used for heating and for cooking.

3.5.2 Definition of policy variants

For the application in the city of Groningen, we specify three policy variants that are actually considered by the municipality, two based on a source of combined aqua thermal energy with aquifer thermal energy storage but with distinct delivery temperatures, and one based on residual heat from the industry with a high delivery temperature (see Table 3.4).

Table 3.4 Definition of the three policy variants for the district-heating system in Groningen

	Variants		
	V1	**V2**	**V3**
Source temperature (degree Celsius)	15	15	50
Heat source	AE+ATES	AE+ATES	Residual heat_industry
Delivery temperature (degree Celsius)	50	70	70
Distance between residual heat source and distribution network (km.)	.	.	5
Lifetime of system (years)	50	50	
Duration of construction (years)	5	5	5
Starting year of construction	2022	2022	2022

3.5.3 Adaptations in houses to reduce heat demand

Depending on the delivery temperature of the heat, houses have to take measures to reduce their heat demand. When the delivery temperature is 70 degrees Celsius, it can be assumed that no measures have to be taken as this temperature is more or less equal to the temperature of existing in-house boiler systems. When the delivery temperature is lower than 70 degrees, the measures to be taken depend on the characteristics of the house, in particular the degree of insulation.

To determine the insulation measures to be taken, the model imposes a requirement for the level of home insulation (i.e. a standard) of the building stock for three different delivery temperatures (i.e. 30, 50 and 70 degrees Celsius), based on Nieman (2021) (see Table 3.5).

Table 3.5 Insulation measures per level of insulation

Insulation level	Required insulation measures	Required for delivery temperature of ...
1	None (this is the current state of insulation)	70 degrees Celsius
2	Floor, roof and cavity-wall insulation with an Rc value* of 1.3, insulated glazing and air sealing.	50 degrees Celsius
3	Similar measures as in previous level, but now with a Rc value of 3.5 through e.g. using higher-quality materials.	30 degrees Celsius
4	On top of the measures of level 3, drastic measures have to be taken, such as facade isolation, triple-insulated glazing in new frames and isolated doors, with e.g. roof insulation of Rc 8.	

* The Rc (Resistance construction) value indicates the degree of heat resistance. A higher Rc value indicates higher heat resistance and thus better insulation properties.

For each insulation level, we estimate the required investments by type of residence using information from TNO (2020)[9] (see Figure 3.3). The investments required for a given building type are, of course, higher for higher insulation levels. In addition, the required investment expenditure for achieving a given insulation level differs among building types. In particular, newer buildings require lower investments as they are better insulated in the prevailing state.

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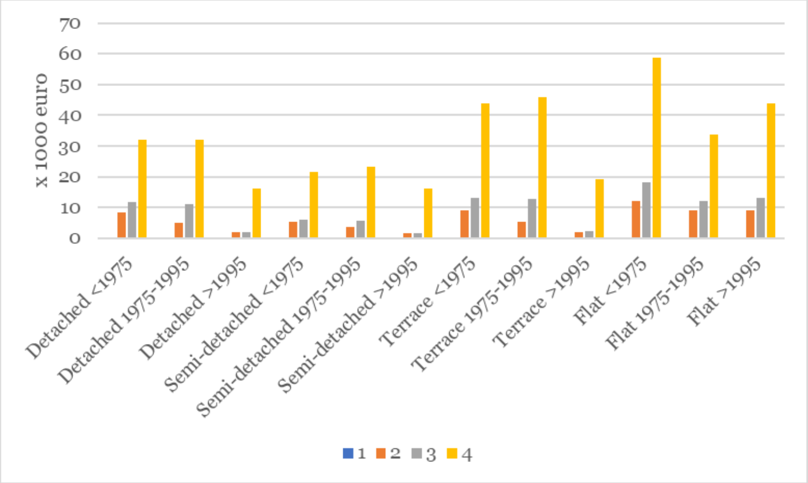
[9] In contrast to our model, TNO in their calculations differentiates between detached residences built <1945 and during 1945-1974. The investment costs for these two groups are relatively similar. Our assumptions for the category detached <1975 are based on TNOs calculations for the category detached 1945-1974.

Figure 3.3 Required investments for insulation, by insulation level and building type (x 1000 euro/house)



Note: Within a building type there is heterogeneity, implying that the actual investments differ among buildings within a building type. The investments shown in this figure reflect the median investment costs (excl. VAT) for each building type, as estimated by TNO (2020).

Besides in insulation, households may also need to invest in low-temperature heat distributors, depending on the delivery temperature. In line with CE Delft (2019), we assume that delivery temperatures of 30 and 50 degrees require the installation of low-temperature heat distributors.[10] Figure 3.4 shows the results for the investment levels.

Given that most residences in the Netherlands use natural gas for cooking and a district-heating implies a disconnection from the natural-gas network, an alternative appliance for cooking is also required. The model assumes that

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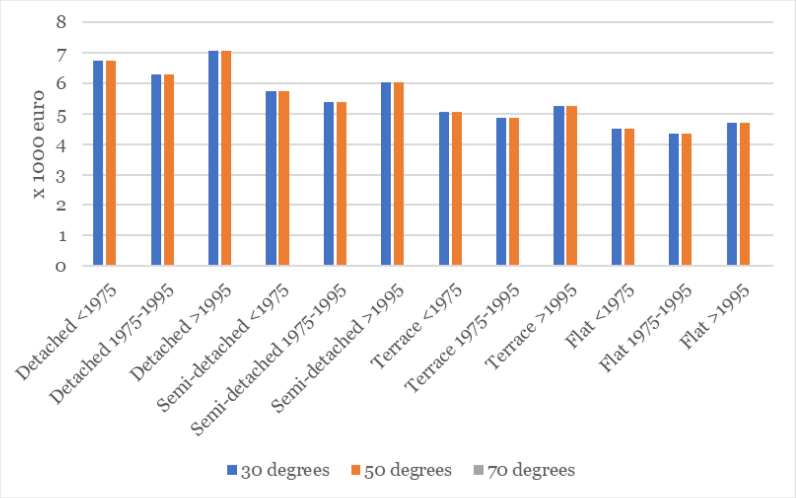
[10] Other low-temperature distributors, such as underfloor heating, are not included in the model. The assumed investments of these low-temperature radiators per residence are set at a fixed investment of €1800 and a variable investment of €34 per m2 of floor space. Information regarding the average floor space by type of residence is extracted from CBS.

residences switch to electricity-based cooking, requiring an investment of €1,000 per residence.

Figure 3.4 Required investments for heat distributors, per building type and delivery temperature



After having estimated the required investments in insulation on the house level, we have to determine the impact on energy use for heating. This impact is estimated based on the relationship between insulation levels, energy labels and energy use. This impact is estimated in two steps.

We first formulate assumptions regarding the relationship between insulation levels and energy labels. In the current situation, all houses conform, by construction of Nieman's (2020) methodology, to insulation level 1.[11] In order to arrive at a higher insulation level, investments are required

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[11] In contrast to the higher insulation levels, insulation level 1 does not reflect a standard but merely reflects the current insulation state. Therefore, at insulation level 1, the insultation properties vary by building type. For instance, newer building types tend to

which results in a lower energy label. Table 3.6 lists the assumptions regarding the energy-label improvement following insulation per type of house.[12] For example, for building type 'Detached - built<1975', insulation level 4 results in an improvement in the energy label by five steps. When the current energy label of this type of house is F, then insulation level 4 results in a new energy label of B.

In the second step, we determine the improvement in energy efficiency for heating that corresponds to an improvement in the energy label, i.e. the relative reduction in heat demand. This estimation is based on data from CBS for the energy use for heating per m^2 by energy label and building type of residential buildings in the Netherlands (CBS, 2020). Table 3.7 lists the assumed gas consumption by energy label and building type.

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be better insulated than older building types in the current state. Hence, newer building types require less measures and investments to increase from level 1 to a higher insulation level.

[12] These assumed relationships between insulation type and energy label are based on the authors judgement, based on the level of the required investments from Fig. 3.3. In general, a larger required investment is supposed to result in a greater improvement in energy label.

Table 3.6 The amount of steps that the energy label is assumed to improve due to insulation, by insulation level and building type

	Insulation level			
Building type	1	2	3	4
Detached < 1975	0	3	4	5
Detached 1975-1995	0	2	3	4
Detached > 1995	0	0	0	1
Semi-detached <1975	0	3	4	5
Semi-detached 1975-1995	0	2	3	4
Semi-detached > 1995	0	0	0	1
Terrace < 1975	0	3	4	5
Terrace 1975-1995	0	2	3	4
Terrace > 1995	0	0	0	1
Flat < 1975	0	3	4	5
Flat 1975-1995	0	2	3	4
Flat > 1995	0	1	1	2

Note: When an insulation level implies an improvement beyond level A, which is the highest energy label, then the model assumes a reduction in heat demand by 2% per incremental step.

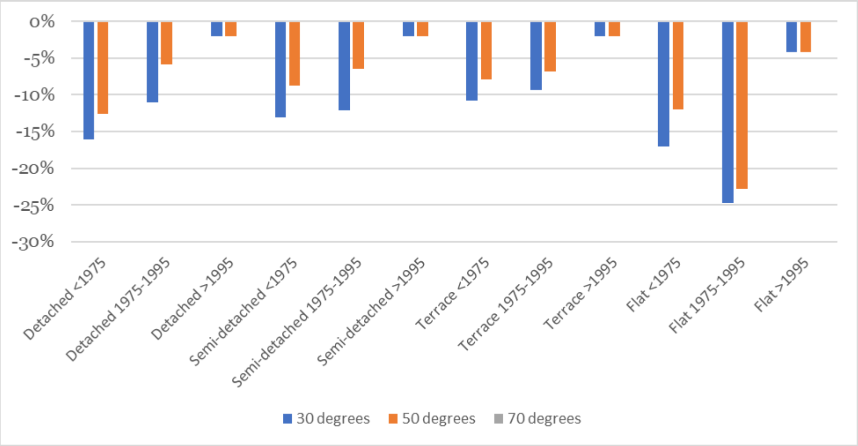
Table 3.7 Gas consumption per house, average per m² per year, by building type and energy label

	Energy label						
Building type	A	B	C	D	E	F	G
Detached <1975	12.30	13.07	13.60	14.63	15.13	15.57	15.60
Detached 1975-1995	11.70	12.10	12.80	13.40	13.60	14.40	14.30
Detached >1995	9.47	10.60	11.45	13.10			
Semi-detached <1975	12.67	13.53	14.20	14.80	15.40	15.57	15.25
Semi-detached 1975-1995	11.50	12.30	13.10	13.90	14.00	14.70	13.60
Semi-detached >1995	9.13	10.10	10.90	11.30			
Terrace <1975	11.37	12.40	12.80	13.40	13.57	13.90	13.67
Terrace 1975-1995	10.20	10.70	11.00	11.30	11.80	12.20	11.45
Terrace >1995	8.17	9.10	9.50	9.85			
Flat <1975	12.00	12.67	13.43	14.40	15.00	15.27	15.62
Flat 1975-1995	11.10	12.20	12.50	14.20	16.20	16.20	14.35
Flat >1995	8.17	9.10	9.50	9.85			

Source: CBS. Gas consumption levels for 'Terrace and Flat >1995 with label D are authors' calculations based on the consumption of label C multiplied by the relative change in consumption of switching form Label D to C for semi-detached >1995.

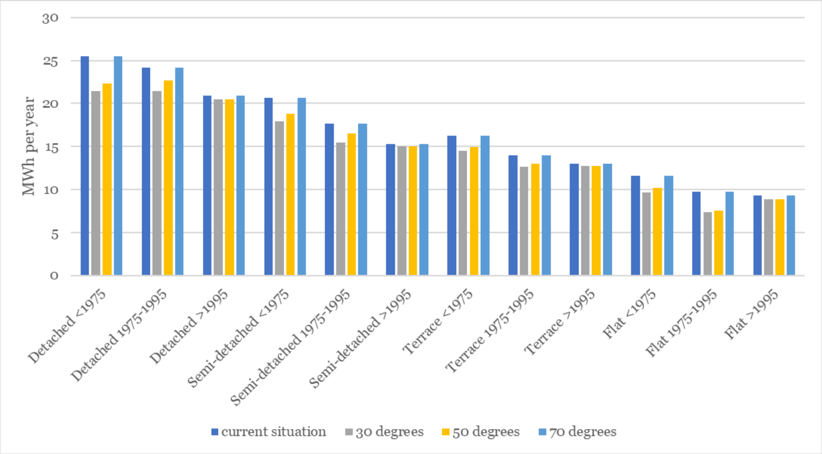
Combining the above information, we are able to determine the change in the energy consumption per type of house in relation to the delivery temperature (see Figure 3.5).

Figure 3.5 Change in energy consumption for heating per type of house in relation to delivery temperature (in %)



The relative change in energy consumption for heating results in a different level of annual energy consumption, depending on the delivery temperature (see Figure 3.6).

Figure 3.6 Heat consumption per residence (MWh), average per household per year, by household type and delivery temperature



3.5.4 Production of heat at building level

When the delivery temperature of the district-heat system is below the current conventional temperature of 70 degrees, we assume that a home-based heat pump may be required to satisfy heat demand during peak times. At a delivery temperature of 50 degrees, the model assumes that buildings with an energy label A or B (which may be achieved through insulation) do not require a local heat pump to satisfy peak heat demand, but require a local “booster” heat pump to satisfy the demand for hot tap water.[13] Buildings with an energy label of C or higher, however, are assumed to require a heat pump to satisfy heat demand at all times with a delivery temperature of 50 degrees. At a delivery temperature of 30 degrees, all buildings require a heat pump to satisfy heat

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[13] Our assumptions regarding whether a heat pump is required at lower delivery temperatures are based on PBL (2020).

demand. In the calculations below, it is assumed that a local heat pump and booster heat pump require an investment of €3800 and €2390, respectively.

The efficiency of the heat hump, measured by the coefficient-of-performance (COP), which gives the ratio of heat output to electricity input, differs between building types, with better-insulated buildings being more energy efficient.[14] The efficiency of the heat pump also differs over time during the year. At colder times (i.e. during peak heat demand) a heat pump is less efficient than on hotter days. Table 3.8 lists our assumptions for the COP at peak times and the average COP during the year (the so-called seasonal performance factor, SPF), by energy label and delivery temperature.

Table 3.8 Coefficient of performance (COP) during peak and on average during the year (SPF) of local heat pumps, by delivery temperature and energy label

	Delivery temperature			
	50 degrees		**30 degrees**	
Energy label	**Peak COP**	**SPF**	**Peak COP**	**SPF**
A			2.5	8
B			1.7	4.2
C+	2.2	5.5	1.1	2.5

Source: CE Delft, own assumptions

Figure 3.7 illustrates the model's results for the amount of heat that is annually supplied from local electricity use through heat pumps by household type and delivery temperature. Notice that, despite that a lower delivery temperature reduces the total demand for heat (because of the required insulation, see Figure 3.6), the greater inefficiency of heat pumps at lower

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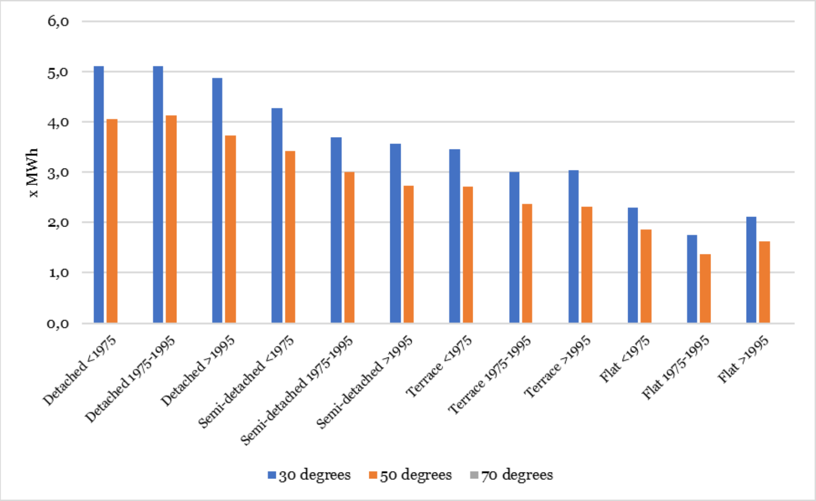
[14] Also the type of heat source appear to influence the COP. Miara et al. (2014) conclude that on average heat pumps using ground heat have a higher SFP than heat pumps using outside air heat.

delivery temperatures results in a higher electricity consumption for local heat production.

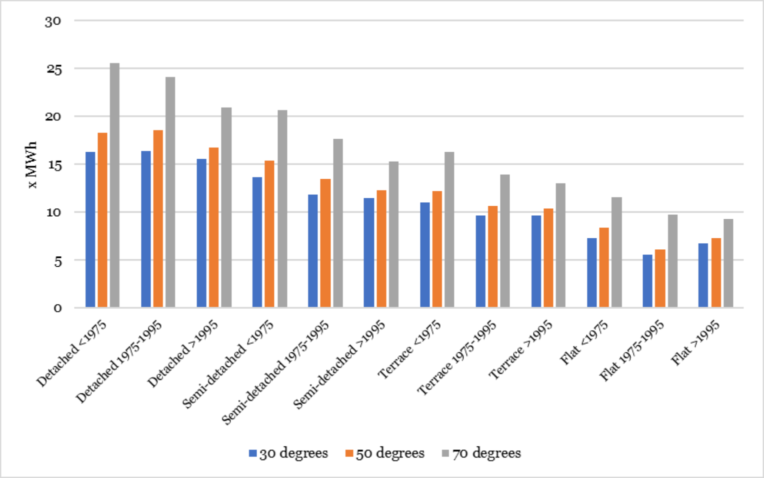
Figure 3.7 In-house heat production by heat pumps, average per household per year (in MWh), by household type and delivery temperature



3.5.5 Required heat from district-heating system

The difference between the heat demand (shown by Figure 3.6) and the own heat production (shown by Figure 3.7), has to be supplied by the district-heating grid. This residual demand is depicted by Figure 3.8. This figure displays, by household type and delivery temperature, the amount of heat that the distribution grid is required to deliver annually, which is equal to total household heat consumption minus local heat production from electricity.

Figure 3.8 Remaining heat required from distribution grid, on average per household per year (in MWh), by household type and delivery temperature



3.5.6 Required system capacity

The required capacity of the district-heating system is determined by the peak demand. Figure 3.9 displays the maximum (peak) consumption on average per household, by building type and delivery temperature.[15] In order to determine the required peak capacity of the district-heating system, we first have to determine the peak heat generated from electricity by the in-house heat pumps. This is shown in Figure 3.10. Based on this, the model determines the required capacity of the district-heating system, on average per type of building (see Figure 3.11). Furthermore, the electricity needed to produce heat in peak hours also determines the required capacity of the electricity grid, which may need to be expanded (see Chapter 7).

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[15] This is based on the assumption that the peak heat demand is four times the average hourly demand. The latter is just calculated by dividing the annual heat demand by the number of hours in a year (i.e. 8760).

Figure 3.9 Hourly peak heat consumption per residence (kWh), per household, by household type and delivery temperature

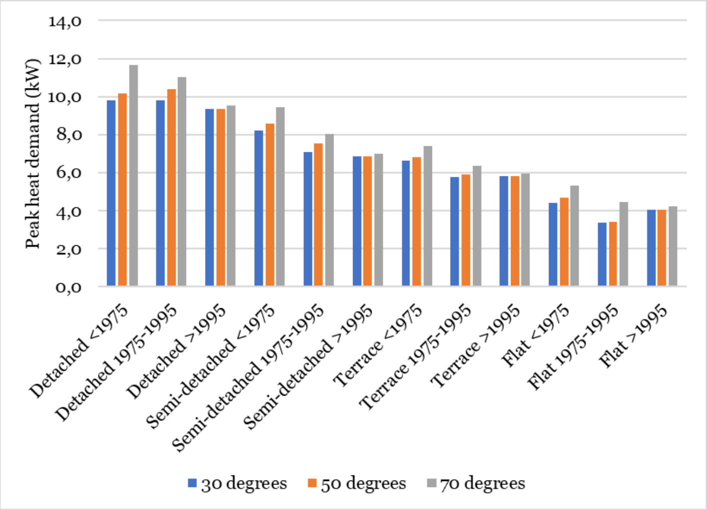


Figure 3.10 Hourly peak in heat production by in-house heat pumps (in kWh), average per household, by household type and delivery temperature

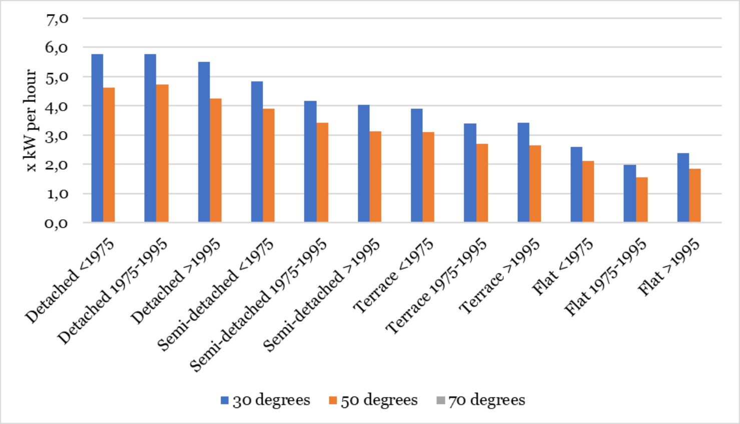
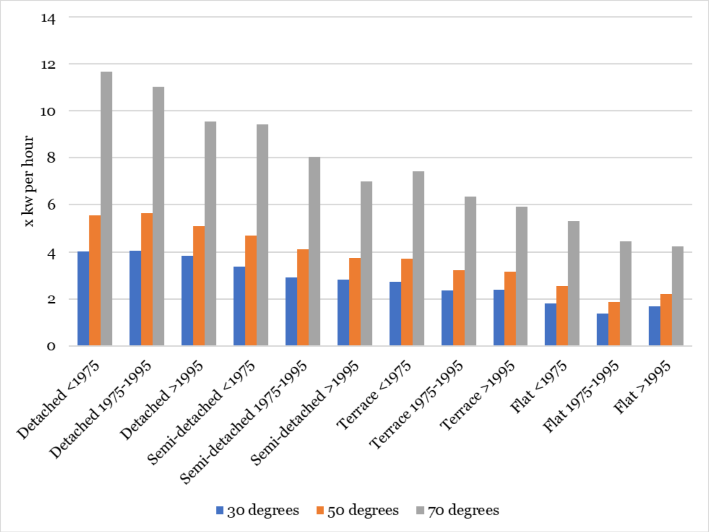


Figure 3.11 Hourly peak amount of heat required from distribution grid (kWh), per household, by household type and delivery temperature



3.5.6 Conclusion

In this chapter, we have defined the policy options regarding the design of the district heating-system and the regional scope of analysis. We have also shown how the choices regarding the design of the heating system determines to what extent adaptations are required in individual buildings and that these adaptations vary across various types of buildings. It is clear that in variant V1, the buildings have to be adapted most intensively because the delivery temperature is below the conventional temperature of 70 degrees Celsius. Figure 3.12 summarizes the investments for the various type of buildings in this variant. Figure 3.13 depicts the total investments in district heating system per variant. It clearly shows that variant V1 requires the larges investments, both in households and to upgrade the electricity grid.

Figure 3.12 Investments in adapting houses, in case of delivery temperature of 50 degrees Celsius, per type of building (x 1000 euro)

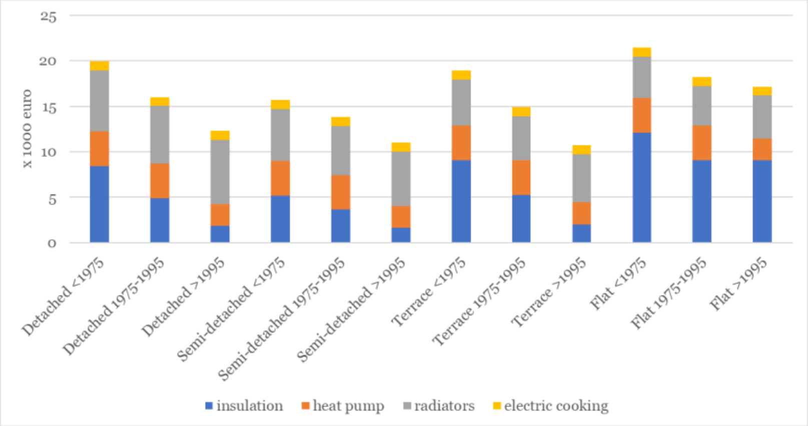
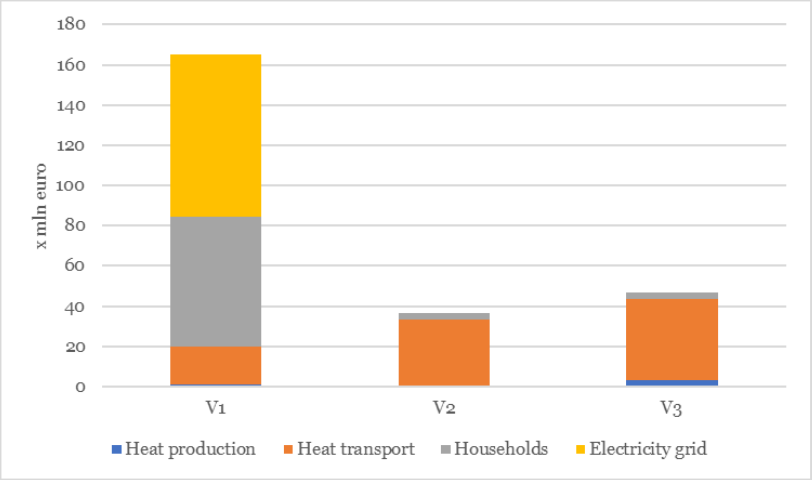


Figure 3.13 Total investments for district-heating system, per category, per variant (x million euro)



4. Definition of scenarios

4.1 Introduction

Before being able to analyse the costs and benefits of the policy variants defined in the previous chapter, we first have to define the circumstances under which these policy variants will be implemented. These circumstances are exogenous to the project, but may have a large impact on the welfare effects.

4.2 Story lines

The welfare effects in a policy variant depend on the assumptions regarding external circumstances, such as energy prices, energy taxes, and the national electricity mix. Preferably, these assumptions are made in an internally consistent way, which results in coherent stories regarding the (relevant) future. In this report, we define three scenarios, which differ in the intensity of (inter)national climate policy (see Table 4.1).

Table 4.1 General definition of scenarios

Scenario	Characteristics
S1	*Modest climate policy*, resulting in stable taxes on the use of fossil energy and high demand for fossil energy, and hence, high prices of gas, and relatively low degree of electrification.
S2	*Intermediate climate policy*, with increasing taxes on the use of fossil energy, and lower taxes on electricity, high degree of electrification and high shares of renewables.
S3	*Intensive climate policy*, with strongly increasing taxes on fossil energy, strongly declining taxes on electricity and a very high degree of electrification, and very high shares of renewables, resulting in low electricity prices

4.3 Translation into values of exogenous variables

These story lines have been translated into values for the various relevant parameters (see Table 4.2). The scenarios define starting values as well as the development paths during the period of analysis.[16] The same holds for the composition of the national electricity portfolio.

Table 4.2 Three scenarios for analysing the welfare impacts of the policy variants

	Scenarios		
	S1	**S2**	**S3**
Prices and Taxes			
Gas price in base year (EUR/MWh)	20	20	20
Gas price development (average annual change, in %)	1.0%	0.5%	0%
Electricity price in base year (EUR/MWh)	50	50	50
Development in electricity price (average annual change, in %)	1.0%	0.0%	-0.5%
Household tax on gas (EUR/m3)	0,3	0.3	0.3
Development in gas tax (in % per year)	0.0%	1.0%	2.0%
Household tax on electricity (EUR/kWh)	0.094	0.094	0.094
Development in household tax on electricity (in % per year)	-1%	-5%	-10%
Electricity tax for non-households (EUR/kWh)	0.05	0,05	0.05
Development in non-household electricity tax (in % per year)	-1%	-1%	-10%
Contribution of national gov't to household investments (per residence, % of investment)	10%	10%	10%
Electricity system			
Share of renewables in 2030	40%	60%	70%
Share of renewables in 2050	60%	80%	90%
Development in share of renewables post 2050 (% per year)	0%	0%	0%
Year of closure of domestic coal plants	2030	2025	2025
Autonomous change in electricity consumption (in % per year)	0.5%	0.5%	1.0%

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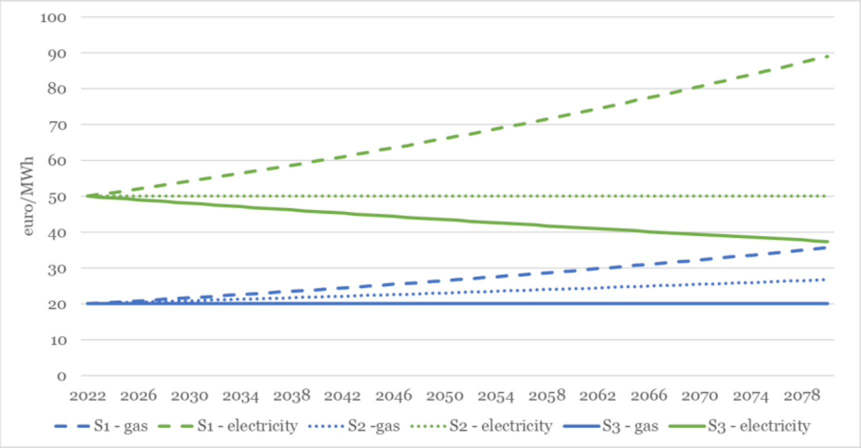
[16] The starting values are based on (average) historical or actual values. The assumed development over time is qualitatively chosen in relation to the story lines. For an 'official' application of the CBA method, these potential future developments should be analysed more extensively. In the sensitivity analysis in Chapter 10, we will show the sensitivity of the welfare effects for a number of scenario variables.

For the projections of future heat demand, we assume an autonomous annual decrease in the demand for heating of 0.5% (reflecting continuing energy-efficiency improvements in buildings over time) in the counterfactual situation (i.e. the null alternative) as well as in the policy variants.

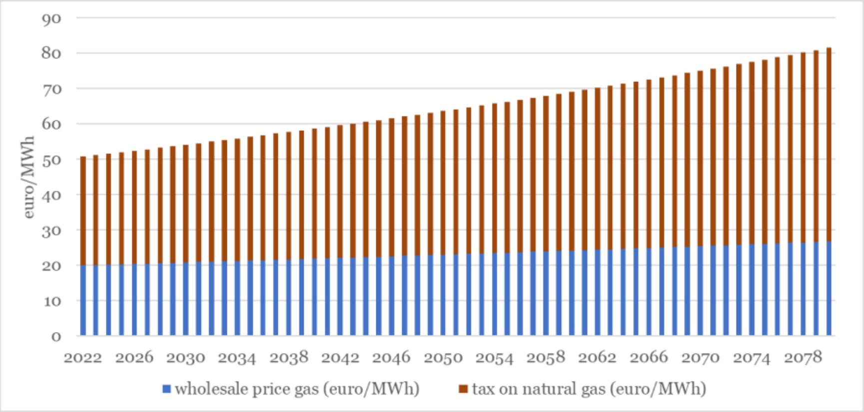
Figures 4.1 – Figures 4.4 show a number of annual values of the variables during the period of analysis 2022-2080. We see that in Scenario S1, both the electricity price and the gas price increase, as in this scenario the electricity price can be assumed to be strongly determined by the gas price, as gas-fired power plants will be the price-setting power plants most of the time. In Scenario S3, the electricity price is assumed to strongly reduce as a result of the (assumed) strong growth in renewable electricity, which also triggers the process of electrification.

Figure 4.1 Gas and electricity wholesale prices, per scenario in 2022-2080 (euro/MWh)



The end-user costs for households of using gas and electricity depend (mainly) on the wholesale commodity prices and the taxes imposed by the government. In Scenario S2, with the intermediate climate policy, we see that the tax on gas gradually increases, while the tax on electricity strongly reduces. In Scenario S3, these developments are even stronger due to the assumed fierce climate policy.

Figure 4.2 Retail gas prices for households, scenario S2 in 2022-2080



The national electricity mix will gradually become more based on renewable (i.e. non-fossil energy based) generation. In Scenario S2, it is assumed that the coal-fired power plants will be shut down in 2025, while the share of renewables will increase to 80% in 2050. In Scenario S3, the share of renewables is assumed to increase to 90% in that year.

Figure 4.3 Retail electricity prices for households, scenario S2 in 2022-2080

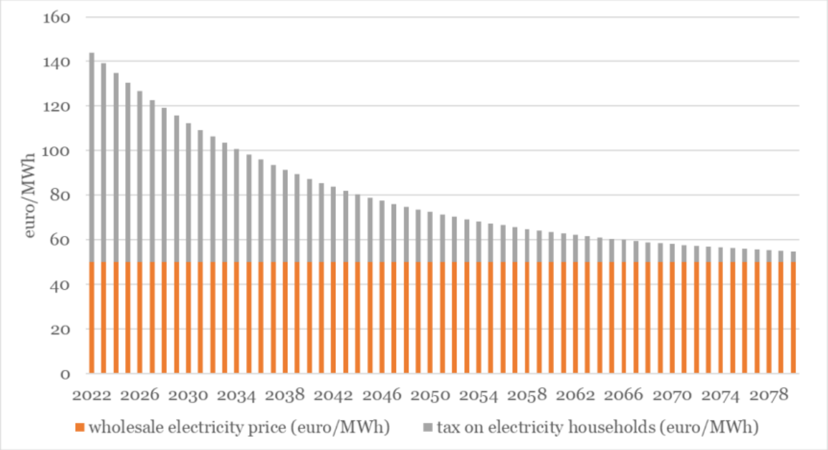
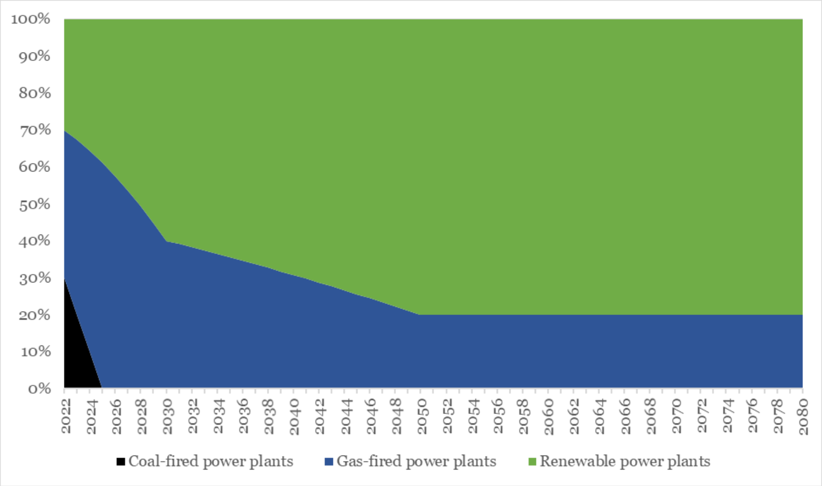


Figure 4.4 Generation portfolio in Dutch electricity market (in %), scenario S2 in 2022-2080



5. Economic effects for households

5.1 Introduction

After having defined the policy variants and the scenarios for the external circumstances, we are able to assess the costs and benefits of the policy variants. In this and the next chapters, we describe these effects for the various stakeholders involved as well as the other (external) effects.[17] This chapter describes the consequences for households.

5.2 Transition to district-heating system by households

In the definition of the policy variant, it is assumed that all houses will make the transition to the district-heat system in five years of time (see Figure 5.1). In the case of variant V1, with a delivery temperature of 50 degrees Celsius, relatively high levels of investments have to be done (see Figure 3.13). Figure 5.2 shows the share of the various building types in the total amount of investments. It appears that the majority of the investments have to be realised in flats built before 1975. As a result of the investments, the natural-gas consumption in this neighbourhood will be fully replaced by heat from the system and electricity used by the heat pumps (see Figure 5.3).

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[17] As said in Chapter 2, the welfare effects are calculated as the present value of the costs and benefits during the period of analysis. In all calculations in this report, we use as a social discount rate 5%. In Chapter 10, we explore the sensitivity of the overall welfare effects for the value of the discount rate.

Figure 5.1 Number of residences connected to district-heating-system over time, variant V2 and scenario S2

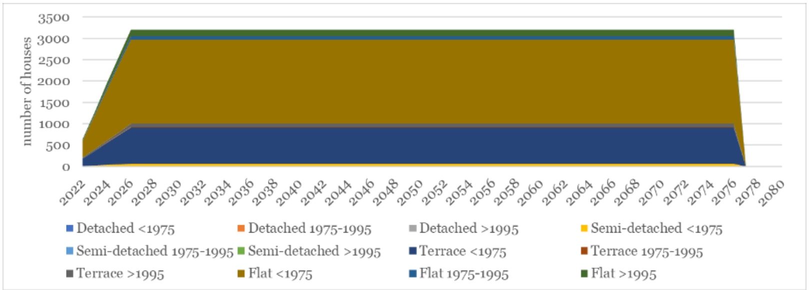


Figure 5.2 Share of building types in total investments in the neighbourhood (in %), in variant V1

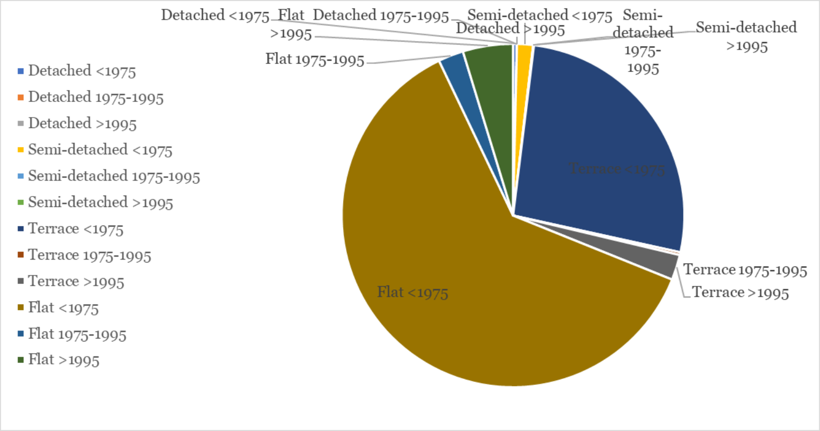
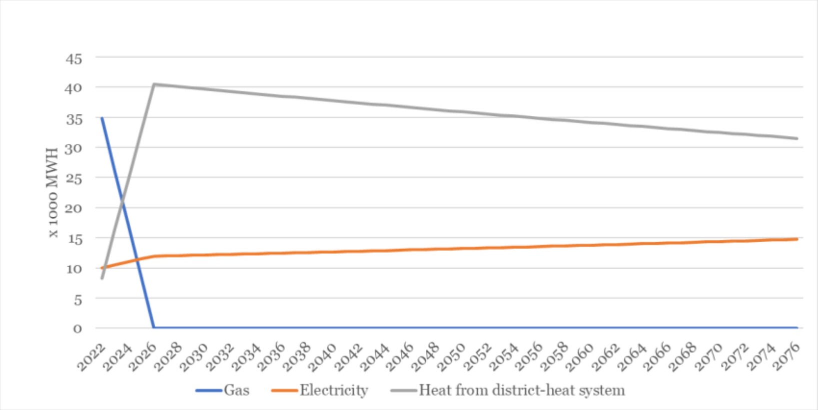


Figure 5.3 Aggregated energy use in region, per type of energy carrier and per year (x 1000 MWh), in variant V2 and scenario S2



The energy use for heating varies strongly among the building types, because of the difference in characteristics (i.e. size, age and degree of insulation) in the starting situation (see Table 3.1). Figures 5.4 and 5.5 show the consumption of heat from the heating system and the use of electricity per building type and variant for the year 2030. In variant V1, the heat consumption is most strongly reduced as a result of the investments in insulation. The electricity consumption, however, strongly increases in variant V1 as all houses are going to use heat pumps. As in both the variants V2 and V3, the delivery temperature is 70 degrees Celsius, the heat and electricity consumption per building type are equal in these variants.

Figure 5.4 Heat consumption, average per house in 2030, per type of building per variant in scenario S2 (in MWh)

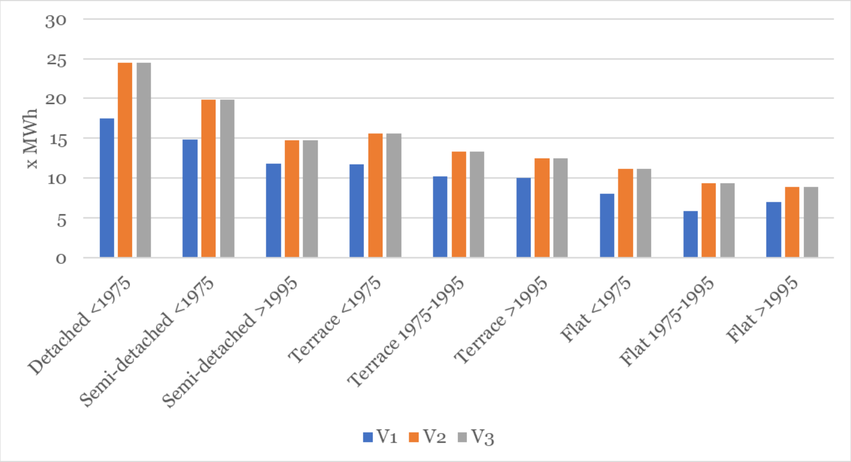
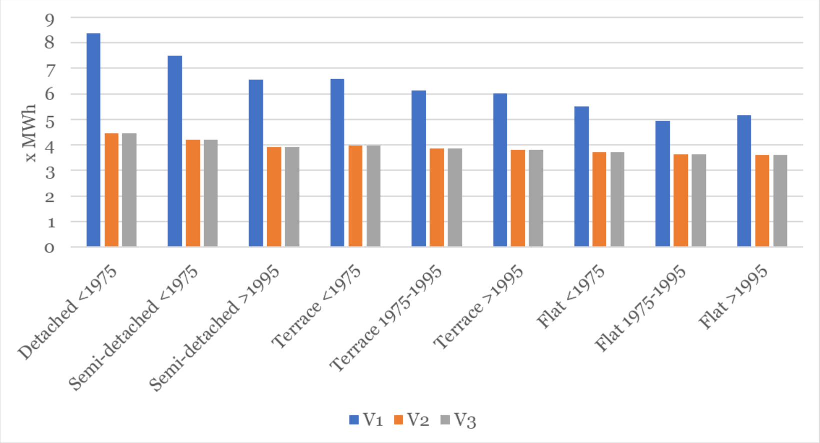


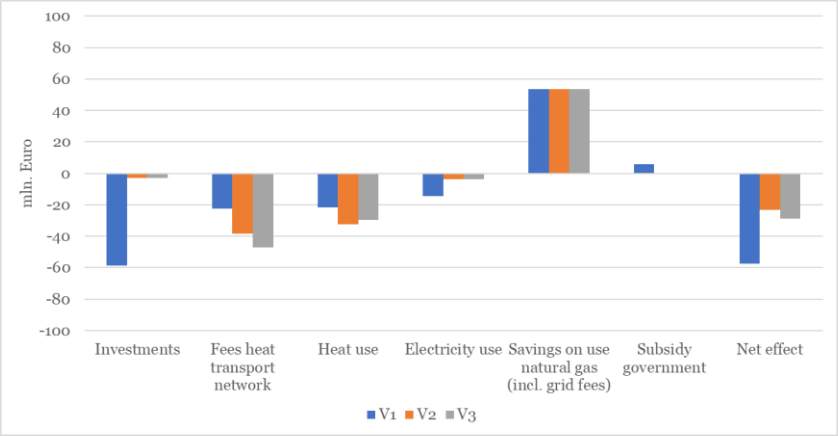
Figure 5.5 Electricity consumption, average per house in 2030, per type of building per variant in scenario S2 (in MWh)



5.3 Welfare effects

The welfare effects for households consists of the investments they have to do (see Chapter 3), the fees they have to pay to the heat-transport operator, the costs of the heat supplied by the heat supplier, the costs for using electricity if they use a heat pump, the savings on expenditures for natural gas and fees for gas transport, and potential subsidies received from the government. As will be explained in the next chapter, it is assumed that all costs of the heat system (i.e. production, transport and delivery) are passed on to the end-consumers.[18]

Figure 5.6 Welfare effects for households, per type, present value in million euro (per variant, scenario S2)



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[18] This assumption is made because we are primarily focussed at the overall welfare effects. When, however, the focus is shifted to the implementation of a district-heating system, the business case for individual players should be positive, otherwise they will not participate. In the final chapter, we will briefly discuss how, for instance, redesigning the energy tax system may help to make district-heating systems profitable for households. Note that even with a positive business case (i.e. benefits exceed costs), there may still be financing issues, as profitability and financeability are two different, though related topics (see e.g. Schellekens et al., 2019).

It appears that in variant V1, the overall welfare effects for households are strongly negative, about 60 million euro, while in the other two variants the net welfare effects are about -/- 20 million euro (see Figure 5.6). This difference is mainly due to the relatively high costs of investments (e.g. for insulation measures) in variant V1. Although the heat consumption is equal in variants V2 and V3, in V3 the consumer fees for heat transport are somewhat higher while the costs for the heat itself are lower because of the lower heat price (see Figure 6.6). This is because the residual heat source in V3 requires relatively high investments in the transportation infrastructure, on which the transport fee is based, as compared to V2, which relies on an aqua thermal source. At the same time, the costs of heat production at the source, on which the heat price is based, are relatively lower for residual heat than for aqua thermal options.[19]

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[19] The next chapter elaborates on the costs associated with the heat system.

6. Economic effects for district-heat system

6.1 Introduction

In the district-heating system, we distinguish three components (or type of agents): heat producer, heat-transport operator, and heat supplier. In practice, these three roles currently tend to be conducted by one player, but in principle they could be done by separate players, as is the case in the other, more developed energy markets (e.g. electricity and gas). For each of these components, we describe the economic effects in the various variants and scenarios.

6.2 Design of district-heating system

The general design refers to the presence of a transport system and the use of collective heat pumps. Investments in these components of the infrastructure depend on both the source temperature and the delivery temperature. Figure 6.1 shows the investments in the system (on average per house) where the delivery temperature is 70 degrees Celsius for various source temperatures. When the source temperature is below 70 degrees, then investments are required in a collective heat pump given a delivery temperature of 70 degrees. It is assumed (see definition of the policy variant), that when the source temperature is at least 50 degrees, a transport infrastructure is required, which is more costly the higher the source temperature. Figure 6.2 shows the investments in the heat system (on average per house) when the source temperature is 15 degrees, but the delivery temperature varies. The higher the latter temperature, the more investments are required for a collective heat pump.

Figure 6.1 Investments in heat system (on average per house) when delivery temperature is 70 degrees Celsius, for various source temperatures

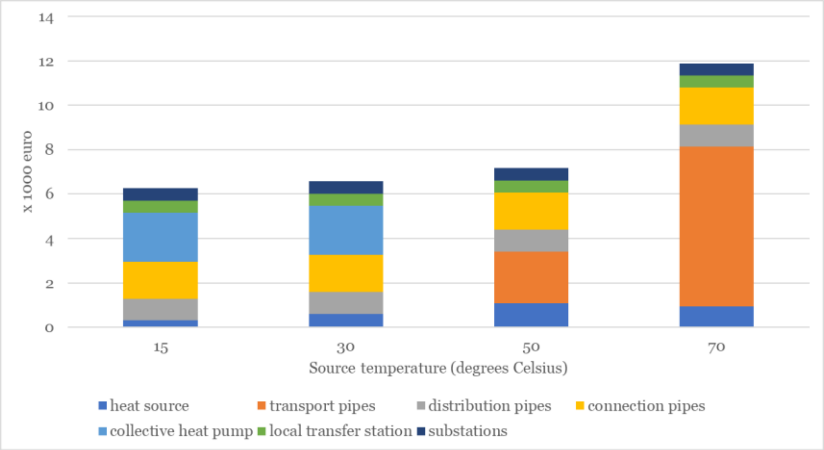
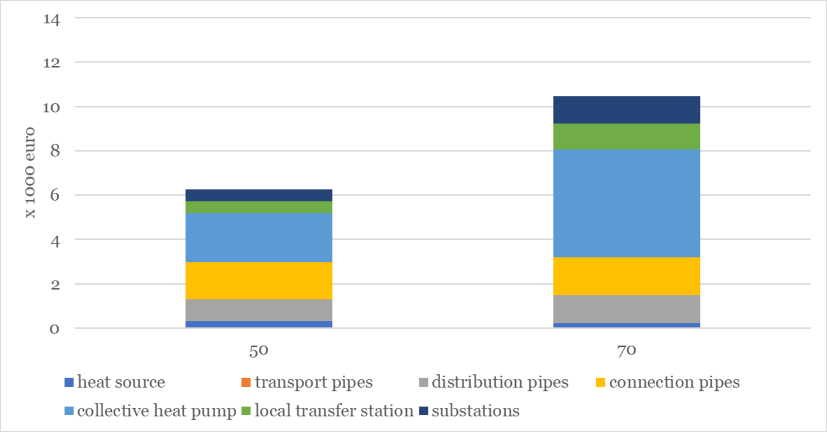


Figure 6.2 Investments in heat system (on average per house) when source temperature is 15 degrees Celsius, for various delivery temperatures



The various heat sources differ in costs. Table 6.1 lists the model's assumptions for the costs associated with the various heat sources, which are based on CE Delft (2019).

Table 6.1 Assumptions for investments per type of heat source

Source	Variable investment costs in euro per kW capacity	Fixed investment costs (x 1000 euro)	Annual OPEX (% of CAPEX)
Aquathermal (AT)	220.0	100	5%
Aquifer thermal energy storage (ATES)	126.5	165	5%
AT+ATES	115.0	150	5%
LT source	250.0		5%
Residual heat from industry	187.5		5%
Residual heat from electricity production	162.5		5%
Geothermal	1875		1%
Bio-based CHP	875		5%

Source: CE Delft (2019).

In addition, when a central heat pump is required, we assume a required investment of €547.500 per MW of capacity (source: PBL). Regarding the efficiency of the central heat pump, Table 6.2 lists our assumptions for the COP at peak times and the average COP during the year (the so-called seasonal performance factor, SPF), for each combination of source and delivery temperature. In general one can say, the larger the difference between the source and the delivery temperature, the lower the COP, i.e. the more electricity is needed to produce the required heat.

Table 6.3 summarizes our assumptions for the costs of the transport, distribution and connection pipelines, which are largely based on CE Delft (2019). As explained in Section 3.2, the transport infrastructure is only relevant when the source temperature is at least 50 degrees Celsius.

Table 6.2 Coefficient of performance (COP) during peak hours and Seasonal Performance Factor (SPF) of central heat pump, by source and delivery temperature

	Delivery temperature (degrees Celsius)					
	30		**50**		**70**	
Source temperature (degrees Celsius)	Peak COP	SPF	Peak COP	SPF	Peak COP	SPF
15	2.5	7.9	1,5	3,2	1.1	3
30			2,5	7,9	1.5	3.2
50					1.75	4.2

Source: Based on CE Delft (2019); authors' assumptions.

Table 6.3 Assumptions for investments in district-heating pipelines, by type

Type of infrastructure	**Fixed investments in euro per meter**	**Variable investments in euro per meter, depending on capacity**
Transport	500	200*(transportation grid capacity [MW])^0.55
Distribution	700	200*(distribution grid capacity [MW])^0.55
Connection	700	200*(avg. dwelling grid capacity [MW])^0.55

Source: Based on CE Delft (2019).

Regarding the heat-transfer station and local distribution stations, based on CE Delft (2019), we assume investment costs of €130 and €135 per kW of heat capacity, respectively.

When heated water is moved through pipelines, heat losses are incurred. The CBA model assumes that the heat loss is higher when the temperature of the water in the pipeline is higher, see Table 6.4 for the specific assumptions. When both transport and distribution pipelines are present in the system, heat losses are incurred twice (i.e. in both types of pipeline).

Table 6.4 Heat loss in pipelines of district-heating system, by water temperature

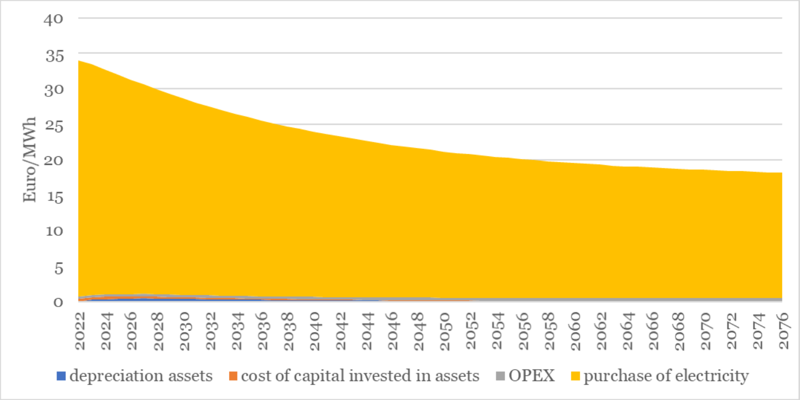
	Temperature in pipelines (degree Celsius)			
	15	30	50	70
Heat loss (in %)	20%	25%	30%	35%

Source: CE Delft (2019), authors' assumptions.

6.3 Costs per type of activity in the supply chain

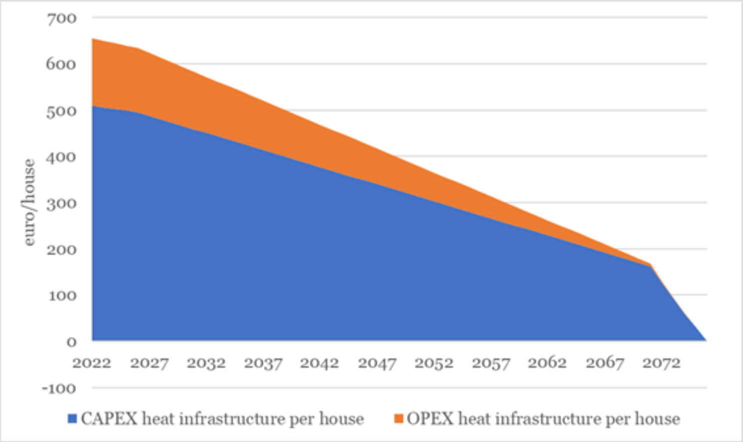
In Variant V2, the costs of the heat source mainly consist of the use of electricity which is used for upgrading the source temperature of 15 degrees to a delivery temperature of 70 degrees (see Figure 6.3). These costs decline over time as it is assumed, in this scenario, that the price of electricity goes down.

Figure 6.3 The costs of the heat source, variant V2 and scenario S2 (euro of MWh produced)



The costs of the transport-system operator mainly consist of the costs of the transport infrastructure (i.e. the CAPEX, consisting of depreciation and costs of capital) and the operational costs of operating the system (see Figure 6.4). The CAPEX are based on the accounting assumption that the asset values are linearly depreciated based on the initial book values. As the annual book value of the asset base declines as a result, the costs of capital decline over time as well.[20] This explains why the CAPEX decline strongly over time. Note that for the overall welfare effect, the method of depreciation does not matter, as depreciation is no more or less than attributing fixed costs to various periods of time.

Figure 6.4 The costs of the transport operator, variant V2 and Scenario S2, in euro per connection (i.e. per house)



We also assume that the transport operator receives the reimbursement of these costs through the tariffs to be paid by households. Figure 6.5 shows the annual transport fees per household, based on the assumptions that all costs

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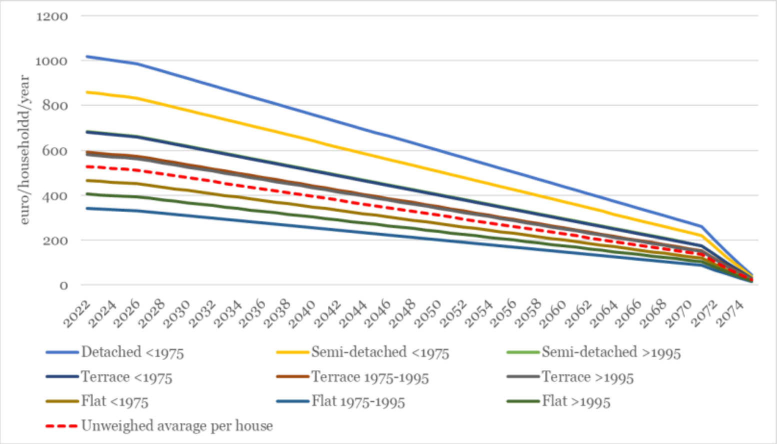
[20] For the costs of capital, we assume the same rate as the social discount rate for calculating the present values. This rate is assumed to be 5% (see also footnote 17).

are passed on to the end-users and that the tariffs are differentiated on the basis of the annual heat consumption per type of building.[21]

Finally, the costs of the heat supplier consists of the costs of buying the heat from the heat producer, its own retail costs, and the costs of heat losses during transport (see Figure 6.6).[22] These costs determine the heat price for the end-user (see Figure 6.7). Variant V2 has the highest heat price because of the use of collective heat pumps to bridge the difference between source (15˚) and delivery temperature (70˚).

Figure 6.5 Transport tariffs per type of building, in variant V2 in scenario S2 (in euro/house/year)



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[21] Note that the assumptions regarding the way the costs of the transport operator are reimbursed only affect the distribution of welfare among agents, but not the overall welfare effect (ignoring behavioural responses). Another option would be, for instance, to assume that the municipality owns and finances the infrastructure and that it raises local taxes (from all inhabitants or only from heat users) to fund itself (see e.g. Monsma, 2020).

[22] Note, that for the final outcome of the cost-benefit analysis, it doesn't matter to which agent the costs of heat losses are attributed. These costs just exist and someone has to pay them in first instance. At the end of the day, the final consumers will pay these costs.

Figure 6.6 Costs of heat supplier, in variant V2 in scenario S2 (in euro/MWh heat delivered to households)

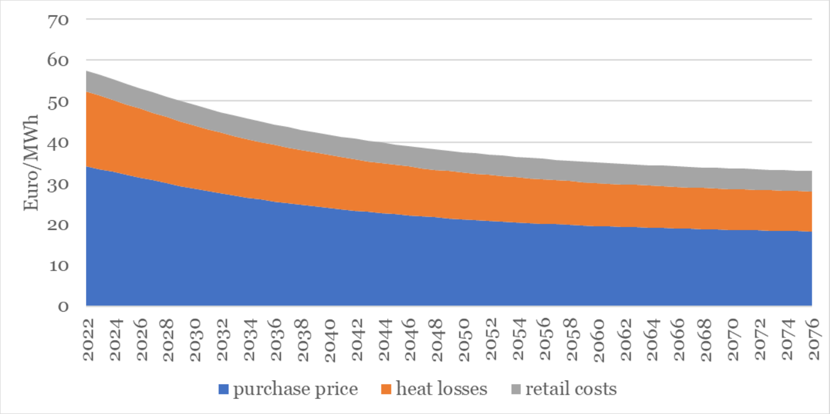


Figure 6.7 Price of heat for end-consumer based on costs of heat supplier, per variant in scenario S2 (in euro/MWh)

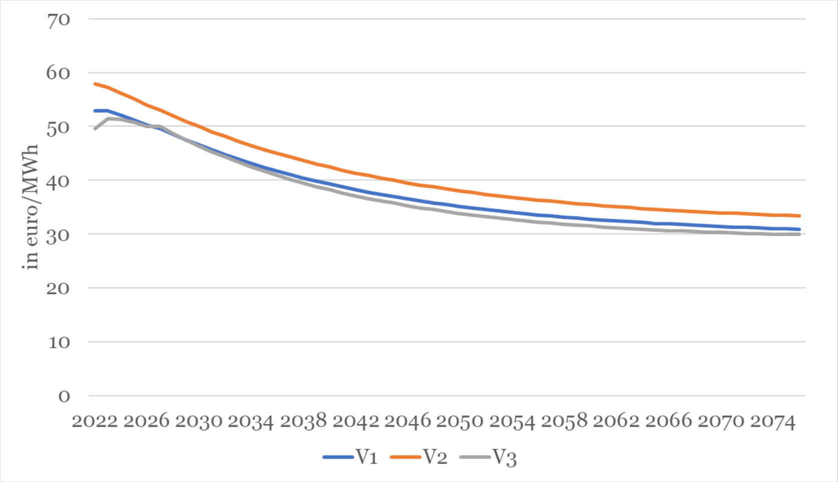
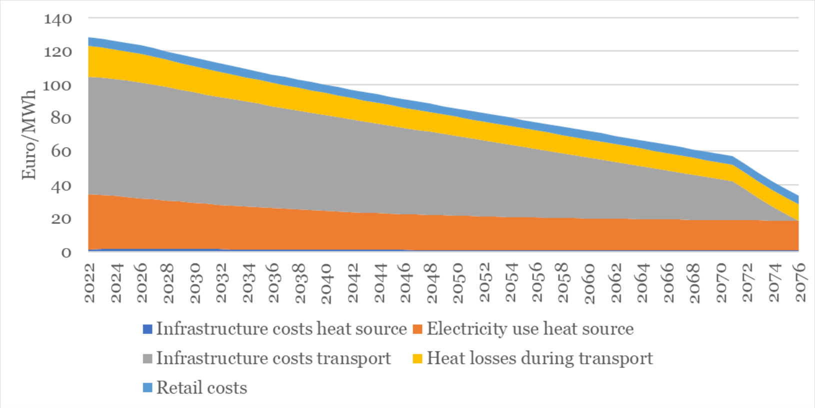


Figure 6.8 summarizes the above cost components in an integrated picture of the system costs of heat supplied to households in variant V2 and scenario S2. These system costs consist of two components: a) the costs of heat, and b) the costs of the infrastructure. The latter costs form the major component of the total system costs. These costs decline over time because both components decrease. The costs of heat decline due to the (assumed) decline in the costs of electricity, while the costs of the transport infrastructure decline because of the assumed method for depreciation (see Figure 6.4).

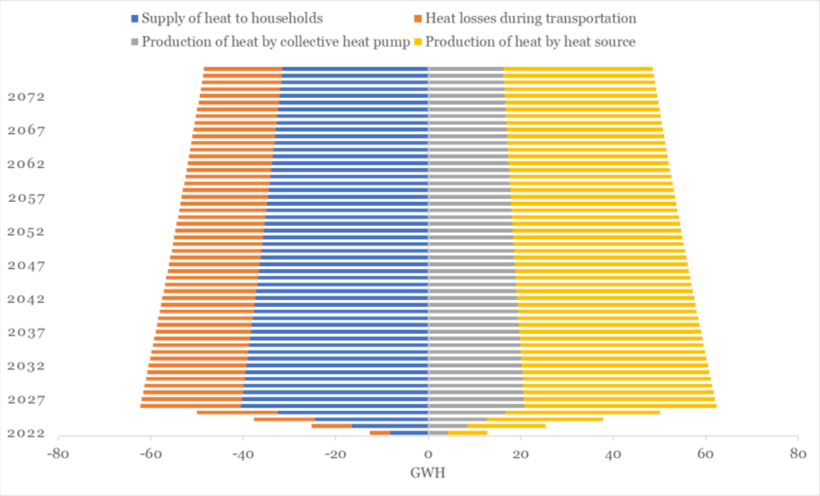
Figure 6.8 Systems costs of heat supply, in variant V2 in scenario S2 (in euro/MWh heat delivered to households)



6.4 *Heat balance*

The performance of the district-heat system in physical terms can be shown by the heat balance. This heat balance shows the origins as well as the destinations of heat and how they develop over time. Figure 6.9 shows that the heat system operates on full capacity after five years (as defined in the policy variant) and that gradually the total production and usage of heat decrease, which follows from the (assumed) ongoing process of efficiency improvements within buildings. The major share of the heat stems from the external source, while the remaining part is produced through collective heat pumps. The left part of the figure shows that a significant share of the heat is lost during transportation, but the major part is delivered to the end-users.

Figure 6.9 Heat balance: origin and destination of heat (in GWh, per year), policy variant V2, scenario S2



6.5 Welfare effects

The welfare effects for the district-heat system can be distinguished in the effects for each of the three components: producer, transport operator, and supplier. Figure 6.10 shows that in all variants, but in particular in variant V2 the major costs of the heat producer consists of the purchase of electricity. As it is assumed that the heat producer can fully pass on these costs to the heat supplier, its net welfare effect is zero. The same holds for the transport operator, who is assumed to be able to fully pass on its costs of the infrastructure to those who are making use of the infrastructure. It is clear that in the variant V3, where a high-temperature source is used, more costs are made for the transport infrastructure (see Figure 6.11).

The welfare effects for the heat supplier mainly depend on the one hand the purchase of heat and on the other, its revenues from selling the heat. As it is assumed that the heat producer can pass on all costs to consumers, it net welfare effect is zero in all variants (see Figure 6.12).

Figure 6.10 Welfare effects for heat producers, per type, present value in million euro (per variant, scenario S2)

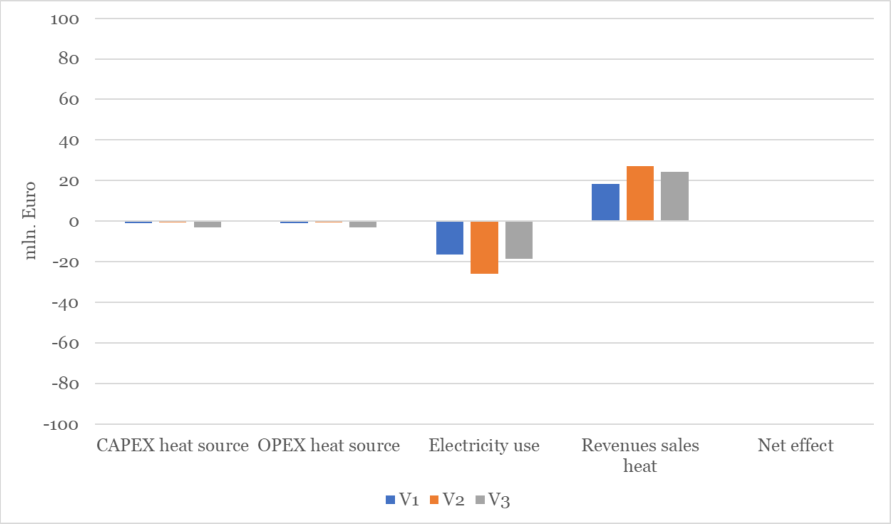


Figure 6.11 Welfare effects for transport operator, per type, present value in million euro (per variant, scenario S2)

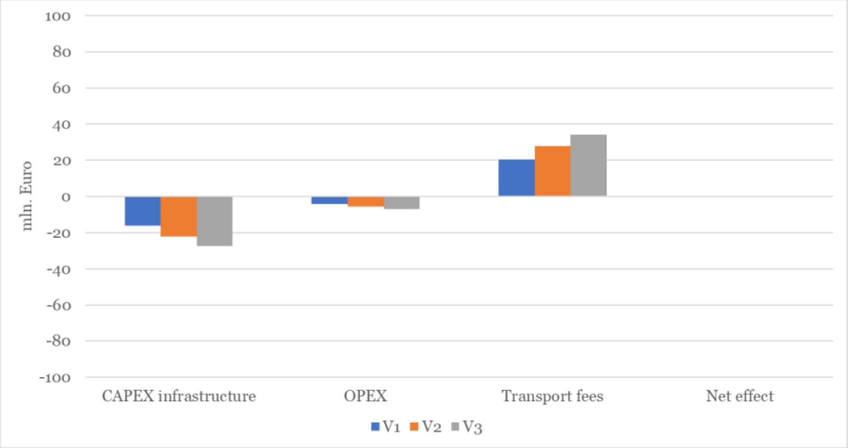
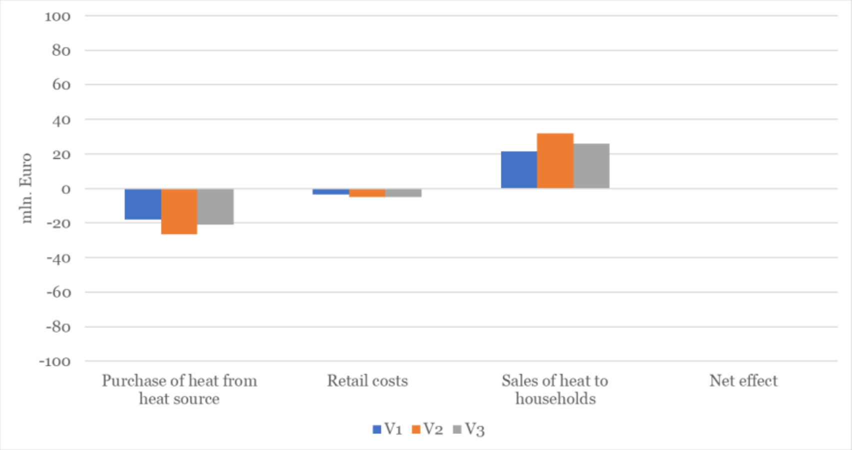


Figure 6.12 Welfare effects for heat supplier, per type, present value in million euro (per variant, scenario S2)



7. Indirect economic effects

7.1 Introduction

The development and use of the district-heating system will also affect economic sectors outside the heating supply chain. This holds in particular for the electricity-network operator, the gas producers, and the gas-transport operator. In addition, there may be an impact on other non-energy infrastructure operators in case infrastructure works in the neighbourhood can be combined. In this chapter, these indirect economic effects are described for each of these groups.

7.2 Electricity network

The electricity infrastructure may be impacted when the district-heating system involves central and/or local heat pumps. As these heat pumps may consume a considerable amount of electricity during peak times in relation to current electricity consumption, we have to account for the requirement to expand the electricity grid. This expansion may in particular be required in case households are installing heat pumps which are connected to the low-voltage distribution grid, while it may be less of an issue for collective heat pumps connected to the medium-voltage grid. Therefore, we assume that electricity grid extension will only be realised when the electricity consumption increases due to installing heat pumps at the building level. The assumed costs for expanding the electricity grid are estimated at €110 per equivalent of the current average household electricity consumption.[23]

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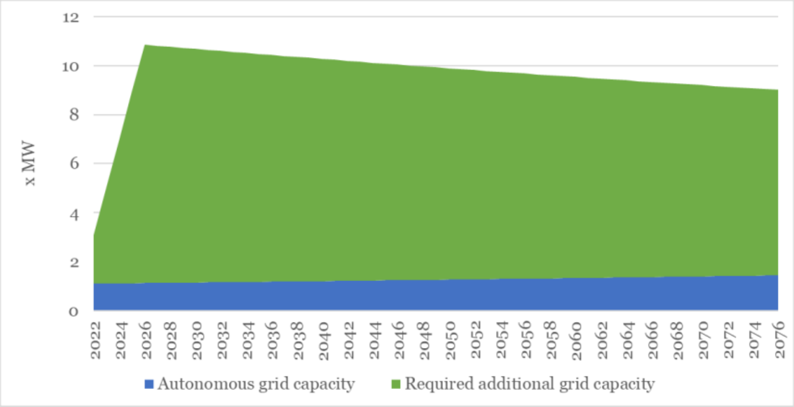
[23] This estimation is based on just two facts regarding the grid of Enexis, which is the distribution-grid operator in the region of Groningen. According to its annual account, its total annual costs of transport and distribution activities are 316 million euro, while they have about 3 million users connected to their grid (see www.enexis.nl). This means that the average current network costs per user are 110 euro per year.

The increase in the required grid capacity (see Figure 7.1) is based on the peak demand for electricity resulting from the peak demand for heat (see Figure 3.10). Note that in variants V2 and V3 there is no increase in peak electricity demand as there is no need to install heat pumps since the delivery temperature in the heating system is 70 degrees Celsius.

The autonomous grid capacity is estimated by assuming that the autonomous electricity demand is constant over time.[24] Combining this with the previous information makes it possible to estimate the relative increase in the grid capacity (see Figure 7.2).

Figure 7.1 Required electricity grid capacity, in Variant V1 and scenario S2 (in MW)



The annual costs of the required additional grid capacity can now be calculated by multiplying the annual percentage increase in grid capacity (see

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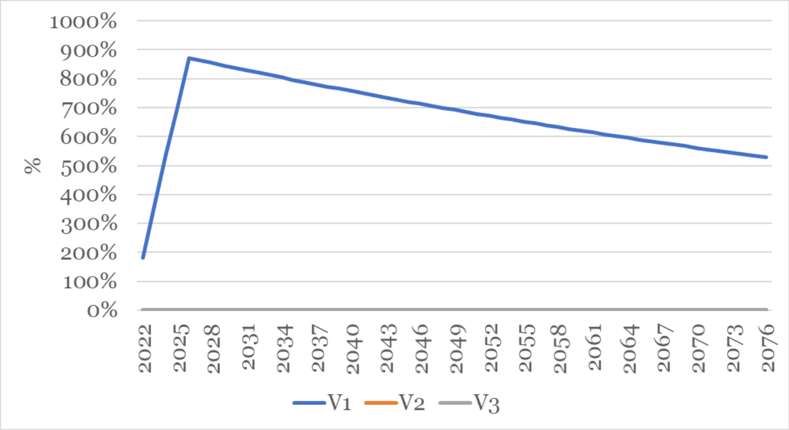
[24] Hence, the autonomous grid capacity is calculated as the autonomous annual electricity demand divided by the number of hours per year, implicitly assuming that the current electricity consumption if flat over a year, which makes sense as this consumption is up to now hardly related to outside temperature.

Figure 7.2) with the current network costs per households (i.e. 110 euro) and the total number of houses (see Figure 5.1).

Figure 7.2 Required additional electricity grid capacity, per variant in scenario S2 (in % of autonomous capacity)



7.3 Gas production and transport

As a result of the switch towards a district-heating system, the gas consumption by households is replaced by using heat and electricity, depending on the delivery temperature in the heating system. When electricity is used by households and/or the heat producer, there may also be an increase in the gas consumption by the electricity sector. Figure 7.3 shows the change in the gas consumption by households and the electricity sector in Variant V1, while Figure 7.5 also shows the net change in the gas consumption. It appears that the gas consumption reduces by about 3 million m^3 per year.

The impact of this reduction in gas consumption on domestic gas production depends on how much gas is produced domestically and how much is imported. Assuming that the domestic gas production will be fully stopped in 2030, the share of import in gas supply will gradually increase to

100% (see Figure 7.4). This means that the reduction in Dutch gas consumption will be shared by both the domestic and foreign producers.

Figure 7.3 Change in gas consumption for heating, by type of consumer, in policy variant V1 and scenario S2

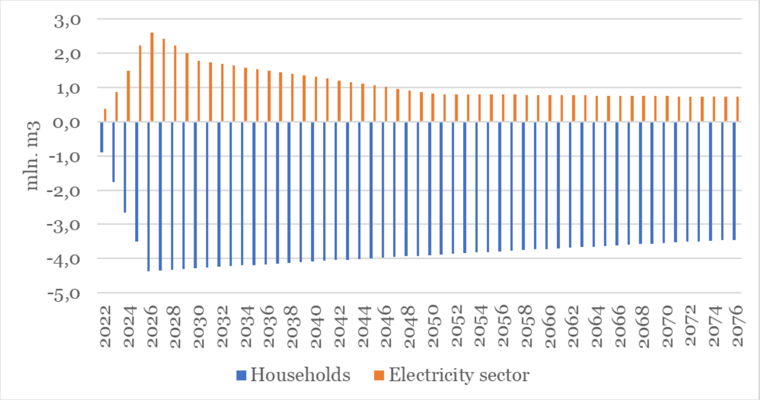
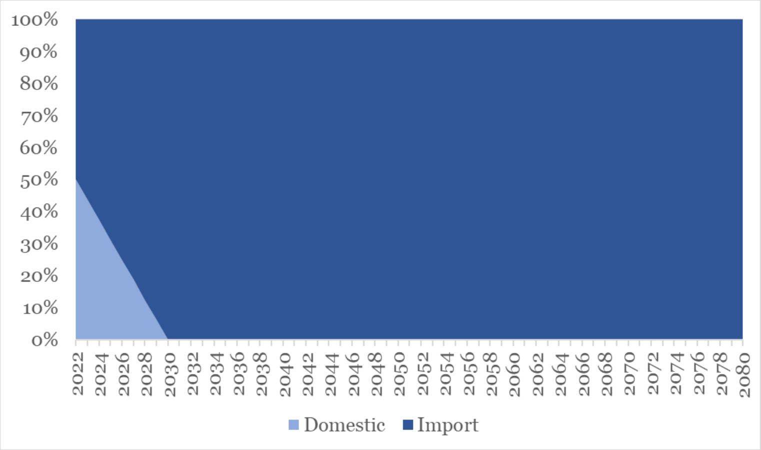
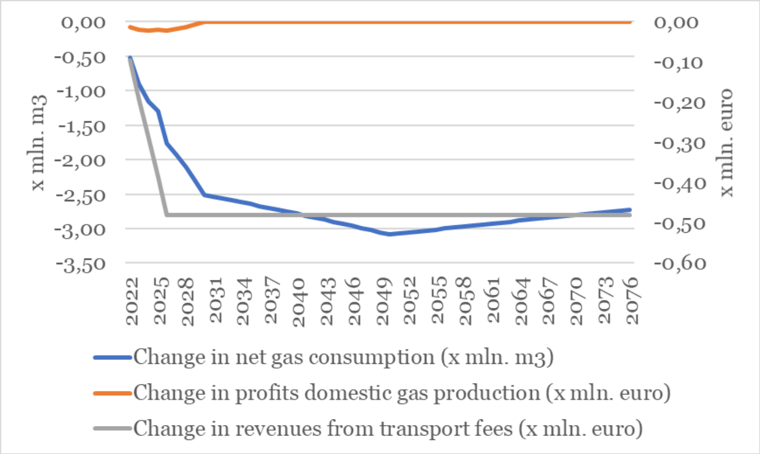


Figure 7.4 Origin of gas supply, variant V1 and Scenario S2 (in %)



Assuming that the profit margin of the domestic gas production is 0.05 euro/m3,[25] and this margin cannot be realised by selling the gas to other customers, we are able to determine the costs for the domestic gas producers resulting from the transition to the district-heating system. These costs amount, in total, to about 1 million euro (see Figure 7.5).

Figure 7.5 Effect on net gas consumption and profits of gas producer and gas transport operator, variant V1 and Scenario S2



Also the gas transport operator will face a loss because of the reduction in the revenues from transport fees. Assuming a transport fee of 150 euro per household, this loss amounts to about 0.5 million per year. Note that this loss for the gas transport operator is a benefit for households. In the remaining, we assume that the gas network is sunk (i.e. costs have been made) and that

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[25] Which is a rough conservative estimate based on the fact that the wholesale gas price used to fluctuate around 0.20 euro/m3, while the Groningen gas producer has relatively low production costs.

no adaptations will be made, although in reality costs will likely be made to remove the gas distribution infrastructure from a neighbourhood with district-heating.

7.4 Other infrastructures

Constructing a district-heating system involves digging in the ground and then paving the road again. This is also required for a number of other types of infrastructure works, such as electricity grid maintenance, replacing water pipelines or building a new fibre network for telecommunication. When digging and paving for the district-heating system can be combined with other infrastructure works, part of the associated costs can be avoided. Here, based on information from the municipality, we assume 40% of the groundworks can be combined with another party, and that for each meter of combined groundwork, 75% of the fixed groundwork costs (consisting of digging and paving) associated with the district-heating network can be shared/avoided. Assuming that the fixed costs are 700 euro per meter (see Table 6.3), the estimated savings are as presented in Table 7.1

Table 7.1 Avoided costs due to combined groundworks with other parties, such as water or electricity infrastructure owners, in variant V2 and scenario S2

	2022	2023	2024	2025	2026
% of district-heating system completed*	20%	40%	60%	80%	100%
Avoided costs for groundworks (x 1000 euro)	87	173	260	347	433

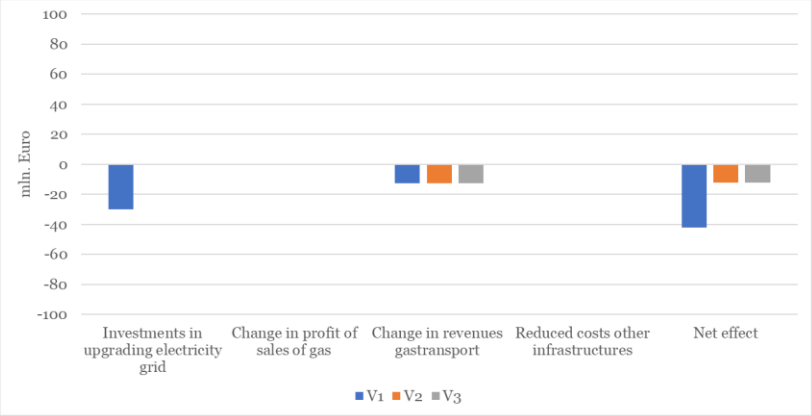
* The duration of the construction is assumed to be five years (see Table 3.4).

7.5 Welfare effects

The indirect economic welfare effects sum up to about -/- 40 million euro in Variant V1 and about -/- 10 million euro in the other two policy variants (see

Figure 7.6). The major effect consists of the costs for extending the electricity grid in Variant V1, which results from the strong increase in peak electricity consumption by households. In all variants, the gas sector faces a loss of about 10 million euro, mainly due to the reduction in transport revenues. Note that on aggregated basis, these latter costs are neutralized, as households benefit from this reduction in gas transport tariffs (see Figure 5.6). From the figure, it appears that the other two types of indirect effects (reduction in profit for domestic gas producer, and the benefits due to combining infrastructure works) are negligible.

Figure 7.6 Indirect economic effects, per type, present value in million euro (per variant, scenario S2)



8. External effects

8.1 Introduction

Policy interventions like the introduction of a district-heating system may also have effects which are not priced in the market, but which do affect the welfare of people. Because these effects are unpriced, they are called external effects. In this chapter, we consider three types of potential external effects: environmental effects, the potential additional value inhabitants attach to a reduction in domestic gas consumption, and the potential additional costs experienced by households when a system requires drastic changes to their homes (i.e. the perceived inconvenience costs).

8.2 Environmental effects

The introduction of a district-heating system which replaces conventional gas boilers may result in lower level of environmental emissions. This refers not only to CO_2, but also NO_x, SO_2, and particulate matter (PM) emissions, as these emissions occur when fossil energy is burned. This holds in particular for coal, but also for natural gas. Therefore, we first have to determine the change in the use of these fossil fuels. Next, we can monetarize them by using so-called shadow prices.

The technical parameters in Table 8.1 are used to calculate the change in CO_2 emissions associated with the change in the use of coal and gas. Figure 8.1 shows the resulting changes in CO_2 emissions by households and the electricity sector in variant V2 and scenario S2.

Table 8.1 Emission factors

Type of emissions	Emission factor
CO2 contained in gas (tonne/MWh)	0.322
CO2 contained in coal (tonne/MWh)	0.181
NOx contained in gas (kg/MWh of gas)	0.4
NOx contained in coal (kg/MWh of coal)	1.8
SO2 contained in gas (kg/MWh of gas)	0.006
SO2 contained in coal (kg/MWh of coal)	1.3
PM contained in gas (kg/MWh of gas)	0.005
PM contained in coal (kg/MWh of coal)	0.07

Source: CE Delft (2017).

To value the net change in CO_2 emissions, we assume a shadow price of €100 per tonne of CO_2.[26] The resulting monetary value of the net change in the CO_2 emissions is given by Figure 8.2. The monetary value is highest in Variant V3, which results from the fact that less electricity is needed in this policy variant, while in the other variants heat pumps are required which result in the use of electricity that is partly generated by fossil-fuel power plants (see Figure 4.4).

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[26] This price is about twice as high as the current carbon price in the European Emissions Trading Scheme (EU ETS), but it is much less that the implied carbon price of the current taxation of the residential use of gas and electricity (see Chapter 9). For the sake of simplicity, we ignore the waterbed effect of the EU ETS and treat all changes in carbon emissions due to the district-heating system as physical effects. Note, there is a large uncertainty regarding the monetary value of these effects. Aalbers et al. (2016) present values in the range between 12 and 1000 euro/ton, depending on the future year and the climate scenario. In Chapter 10, we explore the impact of alternative carbon prices for the overall welfare effects.

Figure 8.1 Change in CO_2 emissions by sector, variant V2 in scenario S2 (x ton)

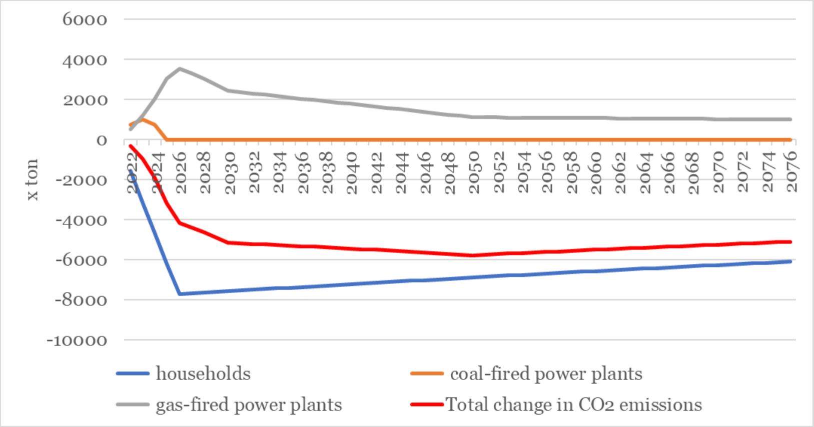
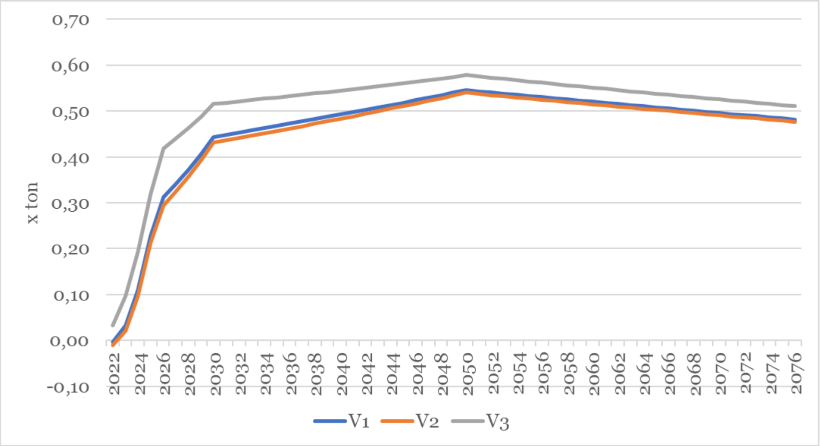


Figure 8.2 Monetary value of change in CO_2 emissions, per variant, scenario S2 (x mln. euro)



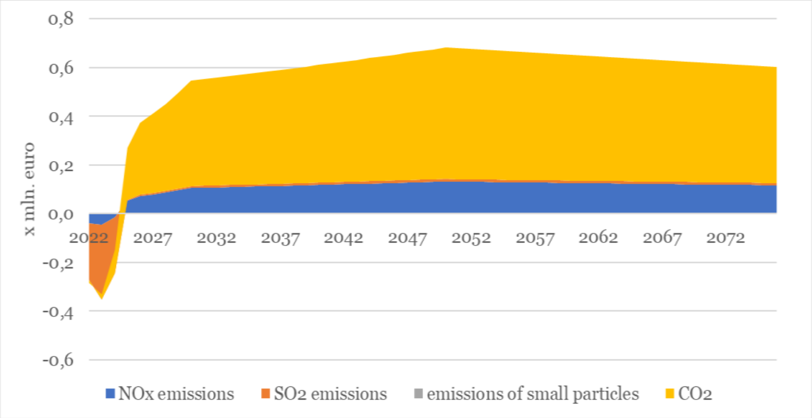
In order to estimate the monetary value of the other environmental emissions, we use the shadow prices given by Table 8.2. The resulting monetary value of the environmental emissions in variant V2 is shown by Figure 8.3. Initially, this value is negative which is due to the increase in electricity generation by coal-fired power plants. After a number of years, these plants are supposed to be closed while the share of renewable generation is increasing strongly (see definition of Scenarios in Table 4.2), which fosters the size of these environmental external effects.

Table 8.2 Shadow prices for non-CO2 emissions

Emission type	Shadow price (€/kg)
NO_x	11
SO_2	58
PM	1

Source: CE Delft (2017)

Figure 8.3 Monetary value of change in environmental emissions, variant V2 in scenario S2 (x mln. euro)



8.3 Societal value of reduced gas consumption

Society (i.e. the municipality of Groningen) may derive value from reducing domestic gas consumption, beyond the other effects in this model. This valuation may stem from the fact that a reduction in gas consumption contributes to a reduction in domestic gas production, which in turn may reduce the associated earthquake problems in the region of Groningen (Mulder & Perey, 2018). The value from reducing gas consumption may also stem from the satisfaction that individuals derive from contributing to a public good (e.g. contributing to the national goal of eliminating natural gas consumption), beyond the impact of their contribution on the public good in question, which is known in the economic literature as 'warm-glow' giving (Andreoni, 1990*)*.[27] In order to capture this effect, the model assigns a value to a reduction of a unit of gas consumption.

Here, we just assume that each m^3 of reduction in gas consumption has a value of €0,10 to society, beyond the value of all other monetized effects. This assumption is relatively arbitrary, as there is a lack of suitable sources for the magnitude of this effect and, hence, further (empirical) research is required to estimate this value.. In the discussion on the overall welfare effects, we will come back to this value by conducting the break-even value.

The highest monetary value for this effect is realized in variant V3, as here less electricity is needed, resulting in a lower overall consumption of natural gas (see Figure 8.4).

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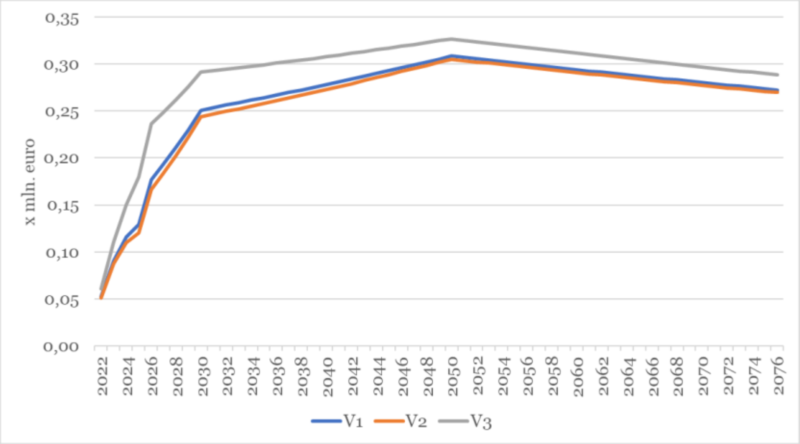
[27] As an example, 'warm-glow' giving suggests that individuals derive value from giving €1 to a charity, even when they know that this contribution directly results in a reduction of the government subsidy for the charity of €1. In our application, there are real effects on emissions and gas consumption, which are also valued in the model, but this example illustrates that contributions themselves may have an additional welfare effect.

Figure 8.4 Monetary value of reduced gas consumption, per variant, scenario S2 (x mln. euro)



8.4 Non-monetary costs of required effort households

Another external effect of introducing a district-heating system may be the effort required by households. The more households have to adapt their buildings, the less utility they may experience.[28] Here, we just assume that for each €1 that households have to invest themselves, they experience €0,10 inconvenience costs. As with the value of reduced gas consumption, this is a relatively arbitrary assumption because of the lack of suitable references for the magnitude of this effect. Further empirical research is required to find a proper estimate for this effect.

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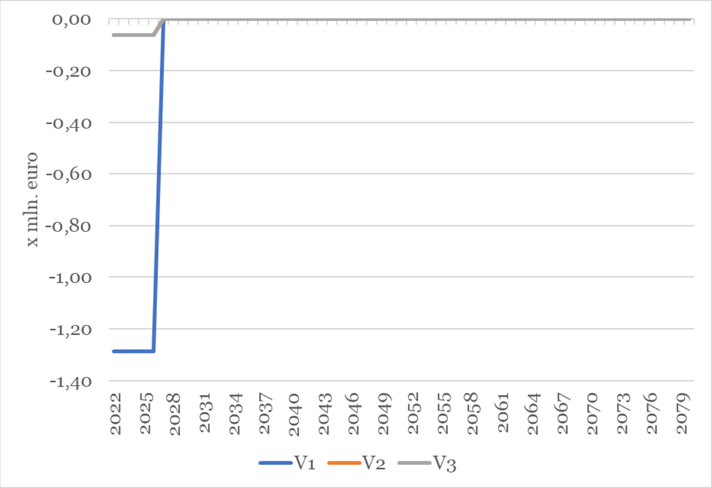
[28] Krikser et al. (2020) find that German households have a preference of being connected to a district-heating system based on renewable heat instead of using a heat pump as they are willing to pay on average value 7 euro per m² extra for this option.

As households in particular have to invest in insulation in variant V1, this variant shows the largest monetary value of these inconvenience costs (see Figure 8.5).

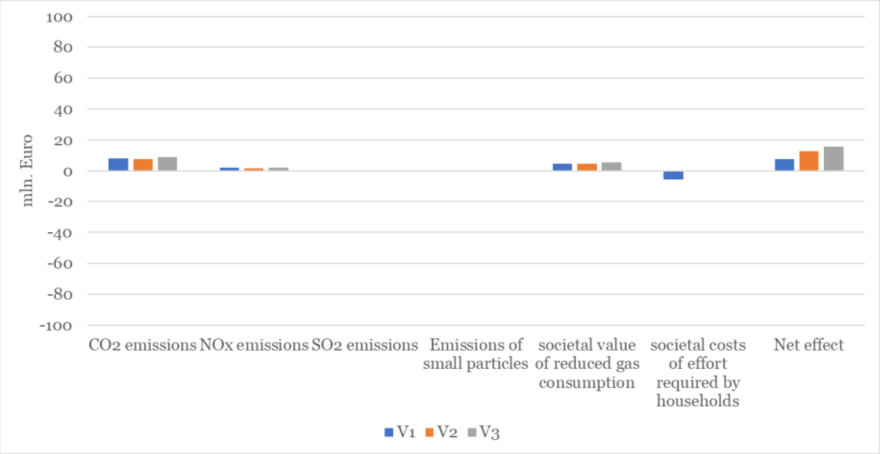
Figure 8.5 Monetary value of effort required from households, per variant, scenario S2 (x mln. euro)



8.5 Welfare effects

Discounting the above external effects over the period of analysis, the aggregated external effect varies between 7 and 15 million euro (see Figure 8.6). The lowest value is realized in variant V1, which is mainly due to two factors: a) the higher usage of electricity, resulting in more environmental emissions, and b) the higher level of investments and, hence, effort required from households.

Figure 8.6 External effects per type, present value in million euro (per variant, scenario S2) (x mln. euro)



9. Economic effects government

9.1 Introduction

Although public authorities may (have to) play a key role in the realisation of district-heating system, in this CBA their role is restricted to giving financial incentives. In this analysis, we only include taxes on the use of gas and electricity, while the government may also give subsidies to households.

9.2 Taxes on energy

As this social cost-benefit analysis is conducted from the perspective of a municipality, the (national) energy taxes are treated as part of the scenarios regarding the external circumstances. These scenarios differ in intensity of climate policy, which is reflected by different patterns of the energy taxes.[29] In scenario S3, with the most intense climate policy, the tax on using natural gas is assumed to increase strongly, while the tax on using electricity reduces strongly (see Figure 9.1). Such a tax design not only fosters the transition away from fossil energy (i.e. natural gas) and towards electrification, it is also more consistent when looking at the implied tax per unit of carbon (see Figure 9.2). The current (marginal) tax on gas for households is equal to about 170 euro/ton CO_2, while the (marginal) tax on electricity for households is equal to about 260 euro/ton CO_2.[30] The latter level is related to the share of fossil-fuel generation. As a result, when the share of renewable generation increases, the (implied) tax per unit of CO_2 will also increase (see Figure 9.3). Hence, a strong reduction in the current tax on electricity is needed to prevent such a strong increase (see also CE Delft, 2021; IBO, 2021; PBL, 2021; Ecorys, 2021).

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[29] Note that all variants depart from the current energy tax levels.

[30] The average tax per unit of consumption of gas or electricity is below the marginal tax because of exemptions up to certain levels of consumptions.

Figure 9.1 Tax on gas and electricity for households, per scenario (in euro/MWh)

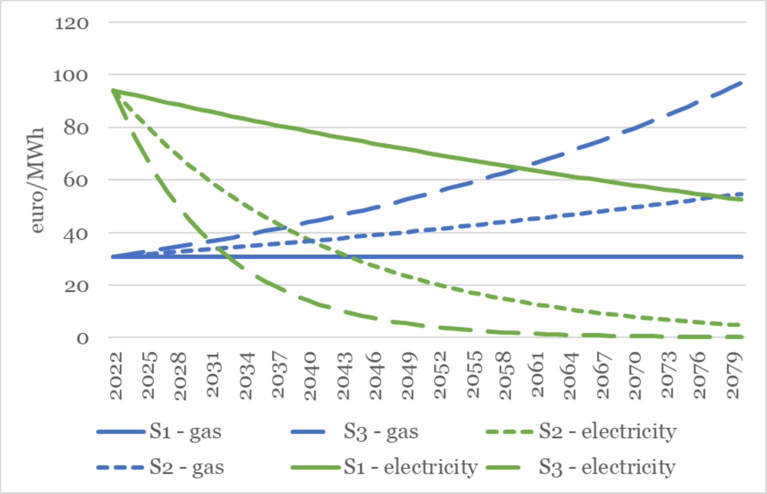


Figure 9.2 Tax on gas and electricity for households (both in euro/MWh and in euro/ton CO_2), scenario S2

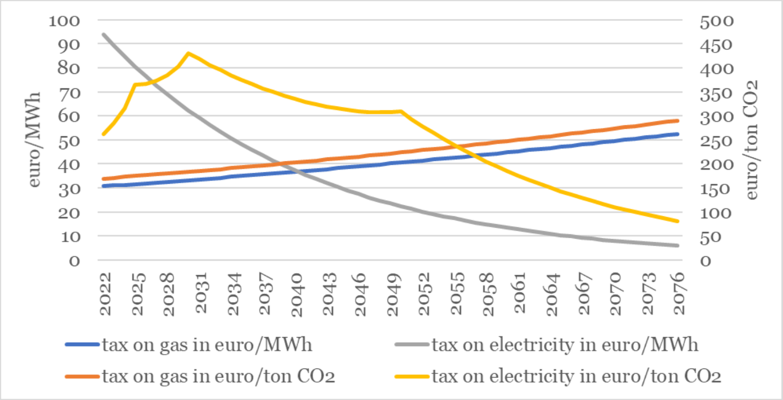
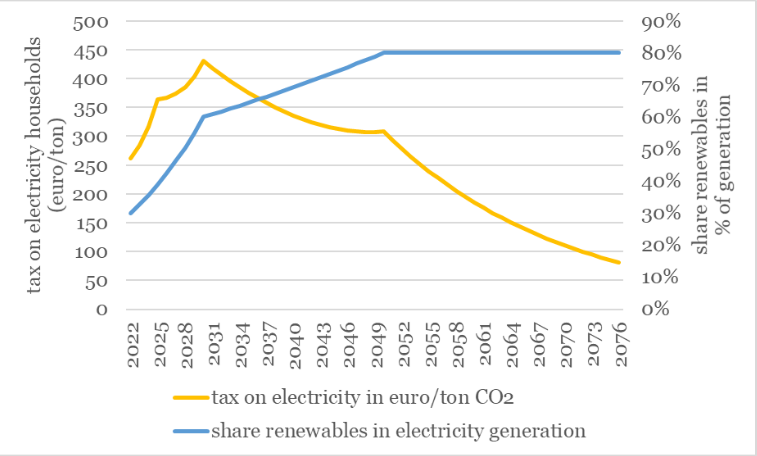


Figure 9.3 Tax on electricity for households (in euro/ton CO2) and share of renewable electricity generation (in %), Scenario 2



9.3 Cash flows government

The introduction of a district-heating system affects the governmental cash flows through the impact on tax revenues from the use of gas and electricity. On the one hand, the government receives less revenues on the taxation of gas consumption, while on the other hand, the tax revenues increase as a result of the increased electricity consumption. This is in particular the case in variant V1. In this variant, households have to invest a significant amount, for which they receive a subsidy of 10% (according to the definition of the scenario). Figure 9.4 shows the overall effects on the governmental cash flows in this variant, which is negative for the government.[31] Consequently, the

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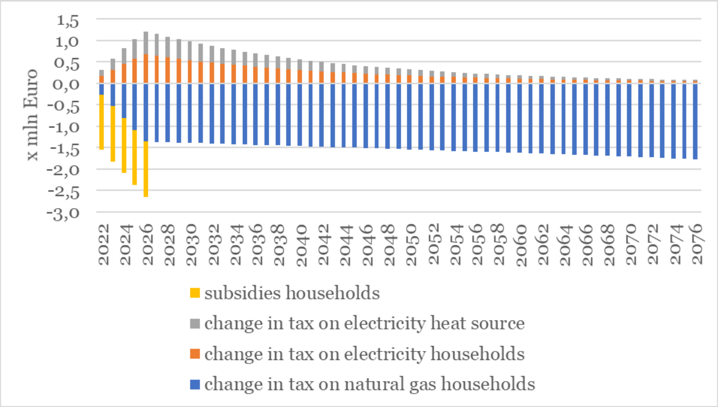
[31] Note that these cash flows only form transfers within the society, which means that they do not affect the overall welfare effect, ignoring transaction costs of collecting taxes and distributing subsidies.

government may need to find another source for its revenues in order to finance this gap, such as raising tax on income from capital or labour.

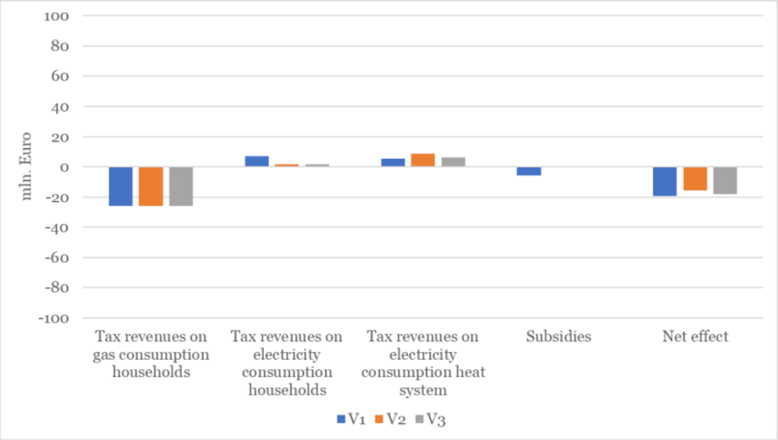
Figure 9.4 Effects on cash flows to and from government, variant V1 in scenario S2 (x mln. euro)



9.4 Welfare effects

The overall welfare effects for the government amount to about -/- 20 million euro in each of the variants, mainly due to the loss of revenues on the consumption of gas (see Figure 9.5). This effect is equal in all variants, as in all of them households are not using natural gas anymore.

Figure 9.5 Welfare effects for government, present value in million euro (per variant, scenario S2) (x mln. euro)



10. Overall welfare effects

10.1 Introduction

By aggregating the above economic effects per group, we find the overall welfare effects. In this chapter, we first present the overall welfare effects per variant and scenario, decomposed into net effects of the various groups. Next, we calculate the so-called break-even values for two external effects. Finally, we conduct a sensitivity analysis.

10.2 Overall welfare effects

The overall welfare effects are presented in Figures 10.1 and 10.2.[32] In the former figure, the background scenario is S2 whereas the latter displays the results for policy variant V2. It appears that variant V1 has the most negative overall welfare effect (-/- 110 million euro), while the welfare effects of variants V2 and V3 do not differ strongly (both about -/- 40 million euro). The relatively large negative effect for variant V1 can be attributed to the large negative value for households, the relatively large negative indirect economic effects resulting from the required extension of the distribution electricity grid, and the relatively small external benefits. [33]

Variant V2 appears to have the lowest negative welfare effect (i.e. is the least negative policy variant), and this effect is even less negative when this policy variant is considered against the background of scenario S3 (see Figure 10.2). In that scenario, there is an intensive (inter)national climate policy, resulting in (amongst others) high taxes on the use of gas, low taxes on electricity, and

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[32] As explained in Chapter 3, we assume that all costs of the heat-supply chain (i.e. production, transport, and delivery) are passed on to the end-users (i.e. households). As a result, the net welfare effect for the groups within the supply chain are zero.

[33] The negative overall welfare effects of the district-heating system is in line with results of CBA studies conducted by Tieben (2020) and most of the policy variants analysed by Menkveld et al. (2016).

high shares of renewable electricity generation. In scenario S1, with a modest climate policy, the welfare effects of variant V2 are more negative. This is partly due to the fact that in such a scenario, the electricity is to a larger extent generated by fossil-fuel plants, which makes that an increased use of electricity hardly results in lower environmental emissions.

Figure 10.1 Net welfare effects of district-heating system, per variant in scenario S2 (x mln. euro)

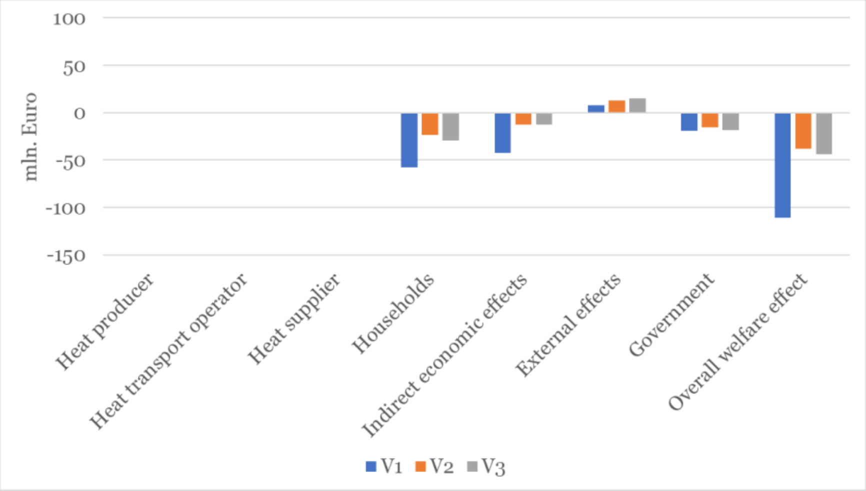
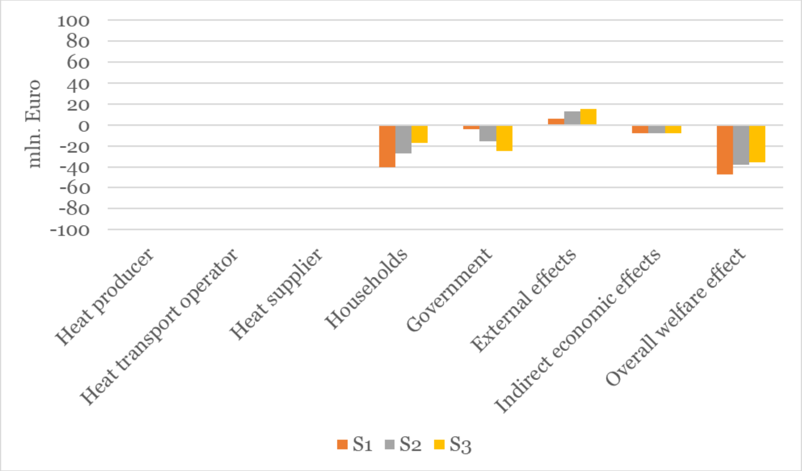


Figure 10.2 Net welfare effects of district-heating system, per scenario for variant V2 (x mln. euro)



10.3 Break-even values of unpriced effects

In the above results, we have assumed a particular value for the external effects of CO_2 emissions as well as the societal value of reduction in gas consumption.[34] Another way of presenting the model results is determining the break-even value for these external values. A break-even value is the price which should be assumed in order for a policy variant to render an overall welfare effect of zero. Figure 10.3 shows that the break-even values for CO_2 emissions differ strongly between variants, but also between scenarios.[35] The lowest break-even values are found for variants V2 and V3 in the scenario with

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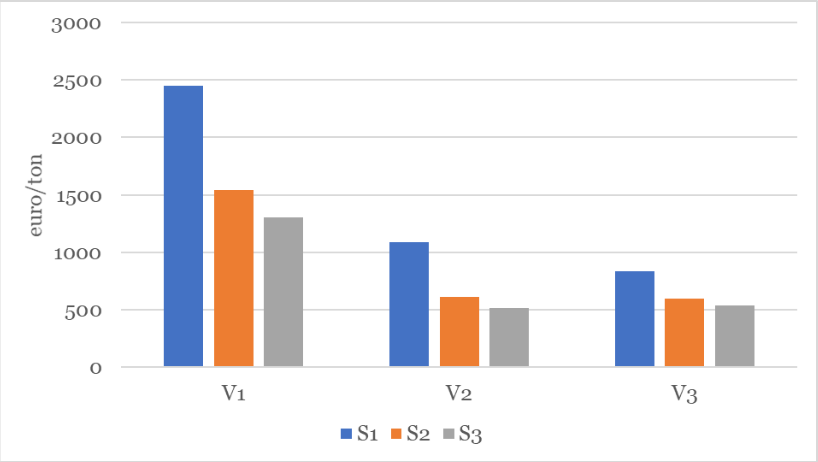
[34] I.e. 100 euro per ton CO_2 and 0.10 euro per m^3 natural gas.

[35] In case of the calculation of the break-even value of CO_2, we assume the default value for the reduction of gas consumption (i.e. 0.1 euro/m^3), and the other way around.

an intensive climate policy (S3). This break-even value is about 500 euro/ton CO_2.[36]

Figure 10.3 Break-even values for CO_2 emissions, per variant and scenario (x euro/ton)



A similar analysis is done for the societal value of reduction in gas consumption. In scenario S3, this value should be at least 0.80 euro/m^3 to make the variants V2 and V3 profitable (see Figure 10.4). In the other scenarios and for variant V1, this value should be significantly higher.

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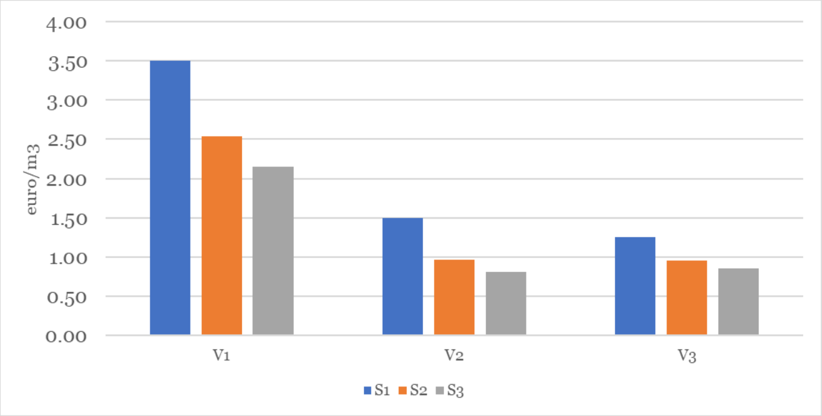
[36] This break-even value is comparable to what was found by Van Melle et al. (2015), who concluded that the costs per unit of carbon emission reduction of heat systems are in the range of 340 to 650 euro/ton. For our variant V1, we find significantly higher costs.

Figure 10.4 Break-even values for societal value of reduced consumption of natural gas, per variant and scenario (x euro/m3)



10.4 Sensitivity analysis

The results are, of course, sensitive to the assumptions made. In all variants, the overall welfare effects are positively related to the gas price (see Figure 10.5) and negatively related to the electricity price (see Figure 10.6). This results from the fact that the introduction of a district-heating system basically means that the natural gas is replaced by heat and electricity. The more costly natural gas, the higher the benefits of replacing that consumption, and, the more costly electricity, the lower the benefits of a transition towards that energy carrier.

Figure 10.5 Overall welfare effect, per variant and gas price, in Scenario 2 (x mln. euro)

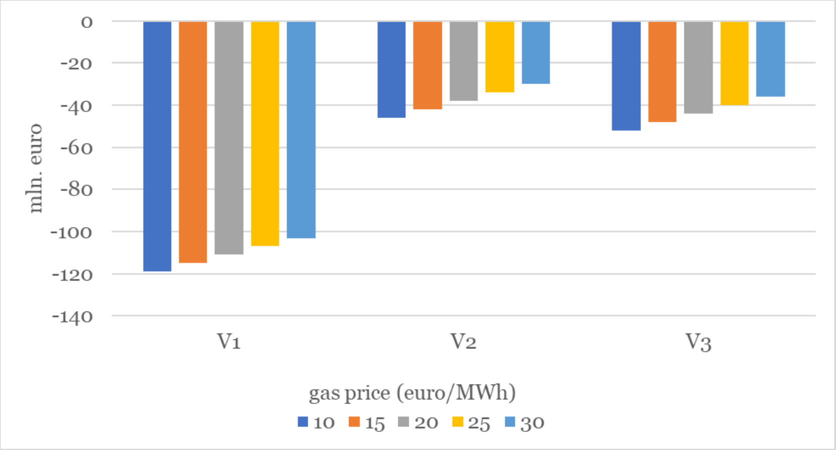
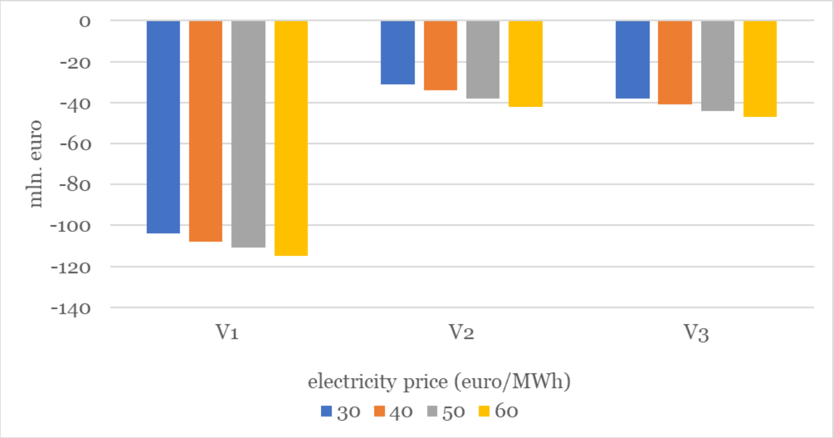
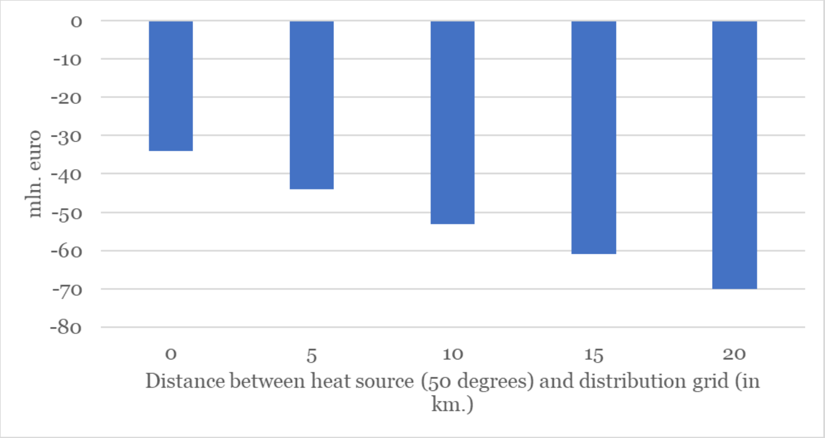


Figure 10.6 Overall welfare effect, per variant and electricity price, in Scenario 2 (x mln. euro)



A particular crucial parameter in variant V3, where a medium-temperature heat source (of 50 degrees Celsius) is used, is the distance between this source and the distribution grid. When this distance is not 5 km., as assumed in the above analysis, but for instance 20 km., the negative welfare effects is almost twice as high (see Figure 10.7). Hence, the distance between heat source and the distribution grid has a major impact on the overall welfare effects of this variant.

Figure 10.7 Overall welfare effect, variant V3 and scenario S2, for various distances between heat source and distribution grid (x mln. euro)



The duration of the construction of the district-heat system also affects the welfare effects. When a longer period of time is used to build the heating system, the negative welfare effect reduces, which is purely an effect of discounting (i.e. costs are shifted to the future) (see Figure 10.8). The same effect results, when a lower discount rate is used, as this means that more weight is given to future cash flows, which mainly consist of benefits (see Figure 10.9)

Figure 10.8 Overall welfare effect, variant V2 and scenario S2, for various durations of construction (x mln. euro)

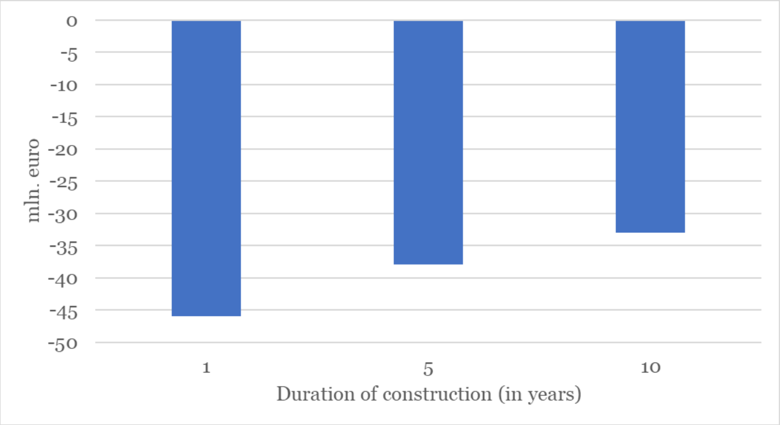
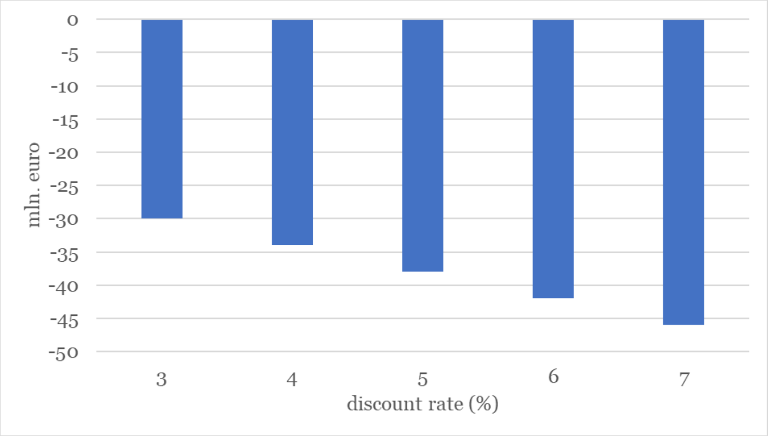
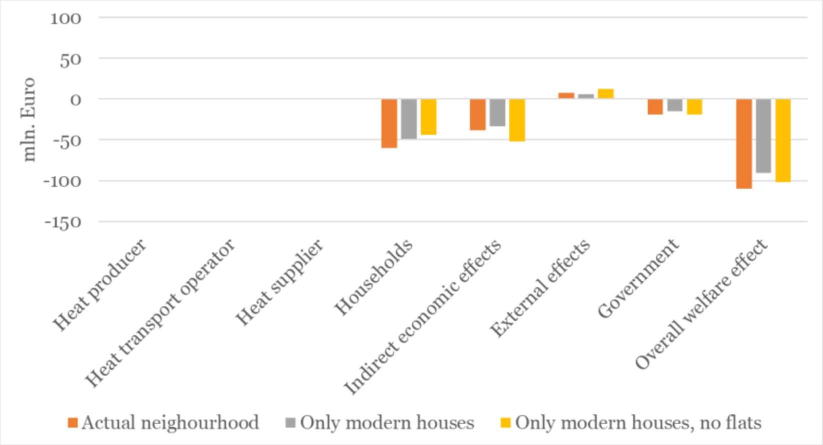


Figure 10.9 Overall welfare effect, variant V2 and scenario S2, for various discount rates (x mln. euro)



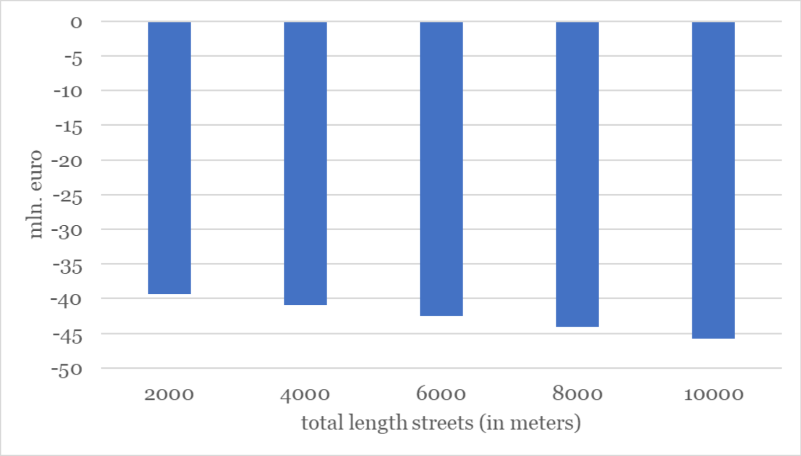
As in variant V1, the welfare effects are strongly affected by the required investments in buildings, which differ among building types. It is interesting to see how sensitive the welfare effects are for alternative compositions of neighbourhoods. Figure 10.10 shows the results when the number of houses per type of building is the same, but when all houses would be modern (i.e. built since 1995). As can be expected, this resulted in lower costs for households (as less investments in insulation are required) and also less investments in the electricity distribution grid as less electricity is needed for the heat pumps. If, however, the neighourhood would only consist of modern houses without any flats, the change in overall welfare effect would be smaller. This is due to the fact that houses (detached, semi-detached or terrace) generally have a higher energy demand for heating compared to appartements in flats.

Figure 10.10 Overall welfare effect, variant V2 and scenario S2, for alternative composition neighbourhood (x mln. euro)



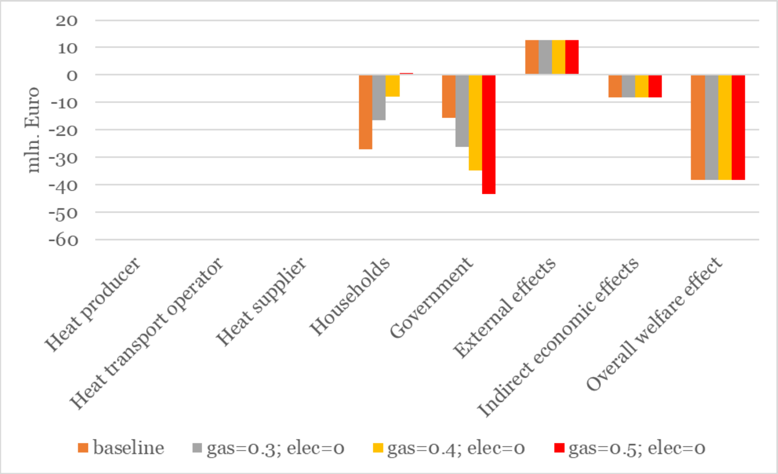
The spatial density of the neighbourhood does not seem to be very important for the welfare effects. Figure 10.11 shows the welfare effects for alternative lengths of the streets in the neighbourhood. Note that a higher length implies a lower density (as the total number of houses remains the same). Variations in this length only slightly affect the overall welfare effects, which implies that the costs of the distribution infrastructure do not form a major cost component (see also Chapter 6).

Figure 10.11 Overall welfare effect, variant V2 and scenario S2, for alternative total length of streets (x mln. euro)



Another crucial economic parameter is the tax on energy. Although a change in the tariffs on gas or electricity does not affect the overall welfare effect, it may make a project profitable for market parties. When the tax on electricity for consumers and heat producers would be fully removed, while the tax on gas for households is raised from the current 0.30 euro to 0.50 euro per m^3 (as is advocated, in conjunction with lower taxes on electricity consumption, by some economists (Eerens et al., 2017; CE Delft, 2021; IBO, 2021; PBL, 2021; Ecorys, 2021), then variant V2 gives a positive net economic effect for all players in the heating system outside of the government (i.e. heat producer, transport operator, heat supplier and households) (see Figure 10.12).[37] This means that under such economic circumstances, market parties are able to exploit such a scheme without any further financial support. Hence, a subsidy on investments in the heat infrastructure, as suggested by IPO (2021), would not be needed, although it may be politically difficulted to raise the tax on gas that much as not all households will be able to shift to another source for heating.[38]

Figure 10.12 Overall welfare effect, variant V2 and scenario S2, for various levels of tax on gas and electricity (x mln. euro)



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[37] Expressed in euro per ton, this would be a tax of about 275 euro, which is about equal to the current tax on electricity for households.

[38] Negative income effects for these households could be overcome by introducing a threshold consumption level of for instance 1000 m^3 as was suggested by Ecorys (2021).

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Acknowledgements

We are very grateful for the support given by the municipality of Groningen to conduct this research. In particular, we thank Marco Attema, Wouter Bolhuis, Paul Corzaan, Klaas Jan Noorman, Anne Venema, Hans Elward (Grunneger Power) and Theo Venema (Warmtestad) for their valuable inputs and discussions during the project. We also thanks the colleagues of CEER for their helpful comments. As usual, the full responsibility for the content of this policy paper lies solely with the authors.

District-heating systems are increasingly considered as means to reduce the carbon-emissions of heating (residential) buildings. In order to contribute to the debate on the desirability of such systems, the authors of this policy paper conduct a social cost-benefit analysis of several variants of a district-heating system in the North-western part of the city of Groningen. They pay attention to the direct economic effects for the various stakeholders (households, heat producer, heat transporter and heat supplier), the indirect economic effects for other stakeholders (such as operators of electricity and natural-gas grids), external economic effects (such as the environmental effects), and the effects for the government (including impacts on energy tax revenues). Based on this analysis, they determine the overall welfare effects as well as the break-even values for the external effects.

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