Enlarge the focus

Linking policy for low-carbon urban heating with sustainable water use and social inclusion.

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Policy brief from the ENLARGE project

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Photo front and back: Pipelines for a district heat network are assembled on a canal. Picture taken by: Chelsea Kaandorp.

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Summary

The transition towards low-carbon heating of buildings is crucial for achieving climate goals, eliminating the consumption of fossil fuel and reducing CO_2 emissions. With the Dutch Energy Agreement, the government of the Netherlands targets to become carbon neutral by 2050.[1] Over the upcoming 30 years, the infrastructural changes that are needed to achieve this will however not only affect carbon emissions, but also the ways in which energy carriers are distributed and how homes are heated. We therefore argue for a focus on the effects of a heat transition that goes beyond reduction of carbon emissions. In this policy brief ‘Enlarge the focus’ we present key insights on the effects of a heat transition on water management and social inclusion obtained during the ENLARGE research project .

Low-carbon heating systems

There are multiple ways to achieve low-carbon or fossil-fuel free heating systems. Examples of infrastructures possibilities for low-carbon heating systems are heat networks, electricity grids for electric heating and transportation systems for renewable fuels. Heating via heat networks or electrical appliances is only fossil-fuel free when the transported heat or the electricity used for heating are not generated from fossil-fuels. The thermal energy for heat networks is generated by the incineration of biomass, or by extracting residual heat from industry and thermal energy from solar, geothermal or aquathermal sources. Examples of renewable fuels are biogas, biomass and hydrogen.

The above mentioned strategies to achieve low-carbon heating systems are usually not stand-alone solutions: they can be used in combination with each other. Several sources can, for example, supply thermal energy to a heat network. These strategies should also be combined with insulation measures; these reduce the heat demand of houses and buildings and therefore support the further reduction of CO_2 emissions.

Sustainable water use

Water plays a key role in energy generation. Water is for example used for the cooling of power plants, storing of thermal energy and production of energy carriers such as biomass and electricity. These processes take place at local and international scale. This means that heat consumed in the Netherlands can have a water footprint on an international scale. If not properly managed, the transition towards low-carbon heating systems could exacerbate water stress or be limited by it. To create sustainable energy systems, water use should be added as an extra dimension in policy making besides reducing costs and CO_2 emissions.

Social inclusion

It is important to watch out for the creation or exacerbation of social inequalities through unequal access to both decision making processes and heating infrastructures. Two concepts that can help to critically analyse social inclusion issues concerning low-carbon heating systems are *energy justice* and *social resilience.*

The concept of energy justice is usually divided into three tenets: distributional, procedural and recognition justice. In other words, the concept is used to describe the distribution of costs and benefits of energy systems, the fairness in decision-making processes and the recognition of different entities and groups relevant for decision-making.

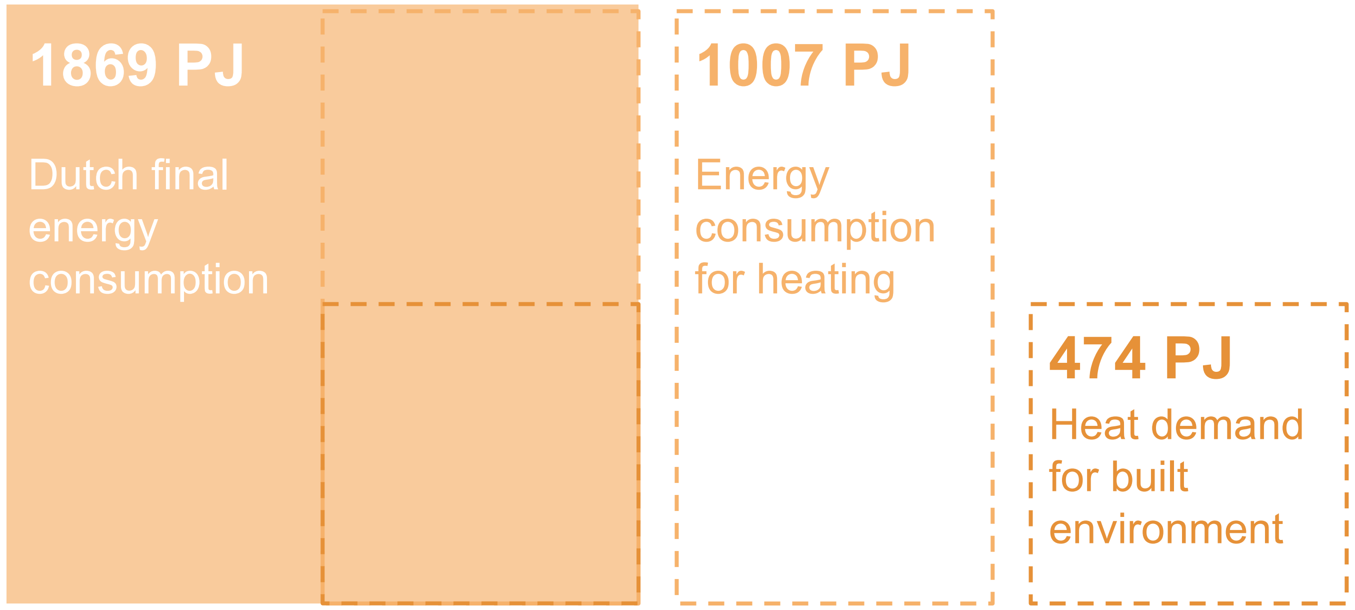
The notion of social resilience on the other hand is used to describe the ability to act together for a common goal. Practices of collaboration, participation and co-creation can be enhanced by: thinking further than traditional sectors, including citizens in public-private agreements, and dissemination of knowledge of success stories and business models of co-creation.

Introduction

The transition towards low carbon urban heating systems is crucial for reducing CO_2 emissions and eliminating the use of fossil fuels by 2050.[1] In the Netherlands, space and tap water heating for the built environment accounts for almost a quarter of the national final energy consumption (see Figure 1).[2] Most of this energy, 85%, is generated from natural gas. Heating consequently generates 13% of the national emission of greenhouse gases.[3] In order to choose low carbon heating systems, energy sector specific criteria are used such as reliability, affordability, and the reductions of CO_2 emissions. However, the impact of the energy transition goes beyond the energy sector. With this policy brief we elaborate on ecological and social considerations that also need to be included in decision making processes around low-carbon heating systems.

The insights from this policy brief are based on a case study performed within the ENLARGE project. The acronym ENLARGE stands for 'ENabling LARGE-scale adaptive integration of technology hubs to enhance community resilience through decentralized urban Water-Energy-Food (WEF) Nexus decision support'. The considered case is about the transition towards heating systems in the Netherlands which do not use natural gas. Through a WEF nexus lense and community resilience concepts, we have identified **sustainable water use** and **social inclusion** as two important considerations for achieving sustainable low-carbon heating systems.

In this policy brief, we summarize our insights on the potential impacts of a heat transition on water use at local and international scales. Additionally, we will describe how concepts such as energy justice and social resilience can help to address marginalization of groups and to remove barriers to collaboration, participation and co-creation. Before discussing the two themes, we start with an overview on low-carbon heating systems.



Figuur 1: The Energy consumption in petajoules (PJ) for heating in the built environment is about a quarter of the final energy consumption in the Netherlands.[2]

About ENLARGE

The main aim of the ENLARGE project is to develop models and tools to facilitate urban decision making processes for innovations at different scales and locations. Central in our analysis is the Water-Energy-Food Nexus. Nexus research is aimed at identifying links between the production and use of different material flows. This makes it possible to identify synergies, trade-offs and risks associated with sectoral transitions. The ENLARGE team assesses the impact of scenarios for metropolitan challenges at decision-relevant scales. In addition to research in the field of economic and environmental sustainability, we also look at questions about social resilience and equity. The ENLARGE team thus works with both mathematical models and social research methods.

ENLARGE consists of an international research consortium (see Figure 2). In the city of Miami, United States of America, we study the role of urban agriculture in fresh food provision, and in the French city of Marseille, we investigate the recycling of raw materials from waste water and the effect of urban vegetation on urban heat islands. The Dutch team focuses on the social-ecological consequences of transitioning towards natural gas-free heating systems in the city of Amsterdam. This policy brief shows insights from this third case study that started in October 2018 and will continue until October 2021.

Figure 2: The ENLARGE team

Low-carbon heating systems

Transitioning towards low-carbon heating systems is an important part of achieving the targets of the Dutch government to almost completely reduce the national CO_2 emissions and the use of fossil fuels by 2050.[1] These goals are not only motivated by climate change, but also the earthquakes caused by natural gas extraction in northern parts of the country. In order to achieve these objectives, different alternative heating systems can be applied. No system is yet to be considered as a one-size-fits-all solution in the Netherlands because of the great diversity in housing types, building infrastructures and spatial availability of heat sources. In this section we give examples of alternative heating systems that are currently being applied in several places in the country.

First of all, heat can be produced by means of electricity or the incineration of renewable fuels. Systems which generate heat from electricity are often referred to as 'all-electric' or 'Power-to-Heat' (P2H) solutions. Such systems can for example consist of heat pumps and Infra-Red (IR) panels. Examples of renewable fuels are biomass, biogas, and hydrogen. Also waste can be incinerated to generate heat. Except for hydrogen fuel, CO_2 is always released during the combustion of these energy carriers.

Moreover, heat can be extracted from already available heat sources. This thermal energy can come from residual heat from industries such as the steel industry and data centers. Thermal energy can also be extracted from the air, water and the underground. In this brief we will refer to the thermal energy from water sources as aquathermal energy. This concept comes from the Dutch word 'aquathermie' which stands for thermal energy from surface, tap and waste water. Thermal energy from surface water is referred to as hydrothermal energy. Hydrothermal energy can be stored in underground thermal energy storage (UTES) systems so that the heat from the summer can be used in

winter. Thermal energy which comes from the core of the earth is referred to as geothermal energy.

Thermal energy can be transported by heat networks with different temperatures. Heat networks, sometimes called district heating, are systems of pipelines that transport hot water (or steam). The temperature of the transported medium can differ per heat network. High temperature (HT) heat networks transport water above 80°C.[4] Medium temperature (MT) and low temperature (LT) heat networks transport water between 65-80°C and 30-65°C, respectively. Very low temperature heat networks (VLT) transport water below 30°C. The advantage of low-temperature heating systems is that more local heat sources can be used.

A consequence of large scale adoption of low-temperature heating systems is the need to reinforce the electricity grid. This is because heat pumps will be needed to raise the temperature of tap water and space heating systems to suitable levels. In the future, the electricity network is expected to be more heavily burdened by electric heating technologies. This means that (peak) electricity consumption will increase and the electricity network may need to be reinforced. The use of hybrid solutions can be applied to limit the burden on the electricity grid. In the Dutch context, hybrid solutions often refer to the use of low-carbon heating alternatives to supply base load heat and the incineration of gas to cover the peak demand.

Retrofit buildings and exploit low-carbon heating strategies

District heating can be a solution with many economies of scale, but achieving decarbonisation goals also requires reducing the energy demand by retrofitting buildings and exploiting low-temperature heat sources. In Amsterdam, district heating is supplied by two heating networks (see Figure 3). This heat is currently generated by the incineration of waste and natural gas. The multiple advantages of this current HT strategy are: supply can always be ramped up to match demand with the combustion of fuels, control of the system is centralized, existing business models can be applied and costs can be limited because no insulation measures are required at building level.

In the long run there may be drawbacks to investing in HT district heating. The costs for heating in non retrofitted buildings can be higher than after insulation. This is because the demand for heat is and remains higher. In addition, there is no certainty about the future availability of high-temperature heat sources that do not emit CO_2. In Amsterdam, there are plans to feed the heat networks with the combustion of biomass and the heat from geothermal energy.[5] It is however not yet known whether geothermal energy sources are suited for development in Amsterdam.[5] If there are no CO_2 neutral sources in the future, the HT heat infrastructure that is now being laid out will still lead to CO_2 emissions in the coming decades.[6] This may prevent the achievement of climate goals. That is why, where possible, other low emission alternatives such as LT heat networks, hydrothermal energy, P2H and hybrid solutions should be used and insulation of buildings should be stimulated.

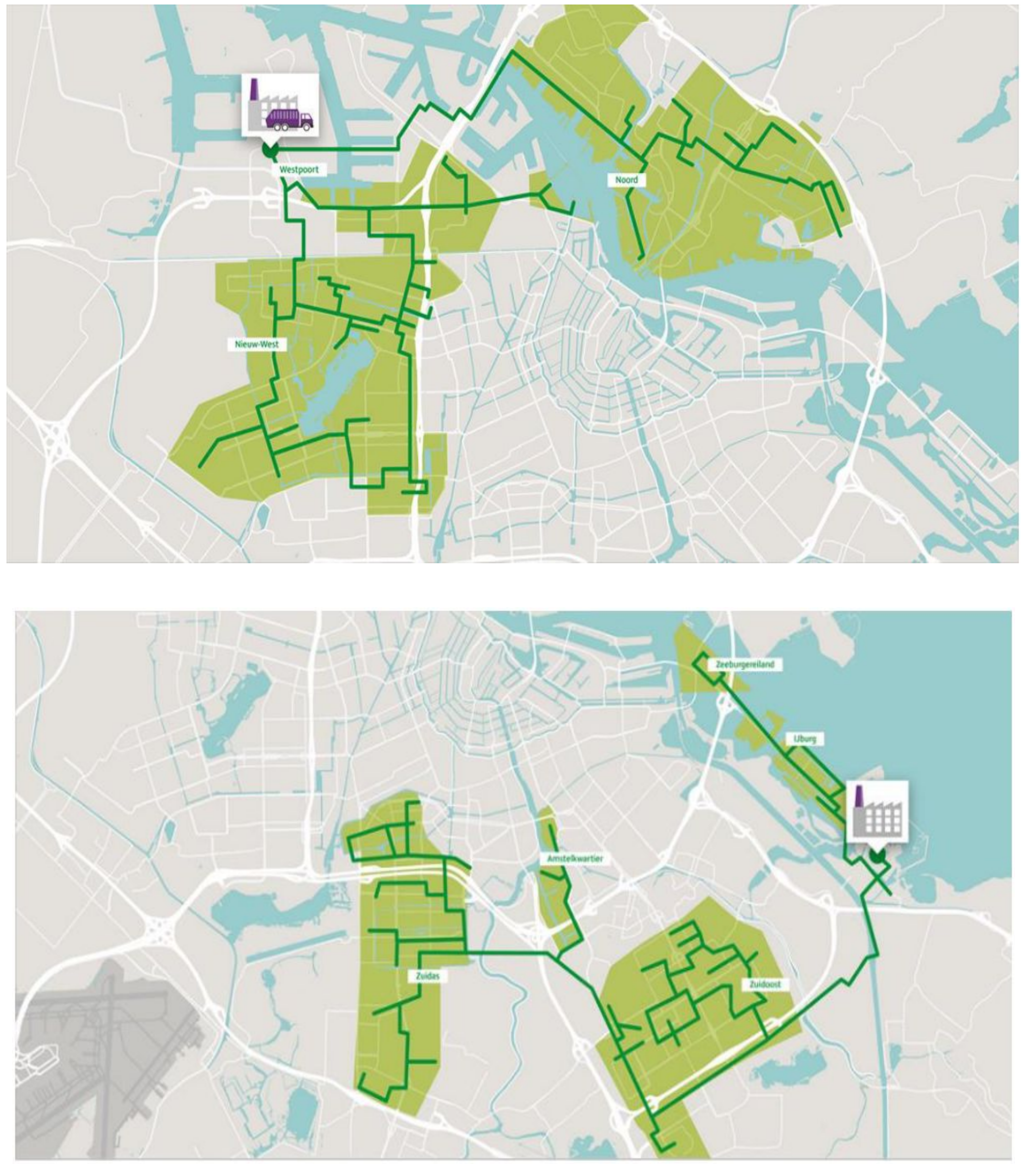


Figure 3: Current high temperature heat network in Amsterdam. Edited picture from Segers et al. (2020).[2]

Water use at local scale

Water is needed for energy generation. If not properly managed, the transition towards low-carbon heating systems could exacerbate water stress or be limited by it. We therefore argue for an increased knowledge on water use for heating systems of the future. **Assessments of the impact of an energy transition on the water use for energy generation are therefore important to secure future energy production.**

In the Netherlands, about 60% of the water that is pumped up is used to cool power plants.[7] This water is heated and returned into the surface water. This discharge of thermal energy influences water temperature and therefore concentrations of oxygen, algae growth and life underwater.[8] Cooling water standards are in place to avoid negative effects of temperature change. These standards can however limit electricity production in hot and dry periods. With the energy transition, the technological mix to generate electricity and heat will change. It is therefore important to update regulations for upcoming types of water use.

In order to see how an energy transition can change the water use of the energy sector, we have developed a model to estimate the water use of electricity and heat production.[9] We have applied this model to energy scenarios for the Netherlands in 2050. Based on the results, we expect that water use for electricity production will decrease in the scenarios in which thermal power plants are replaced by wind and solar energy. On the other hand, **more water withdrawal is expected for the supply of heat due to an increase in Aquifer Thermal Energy Storage (ATES) and hydrothermal energy extraction** (see Figure 4 for a depiction of the operation of ATES and hydrothermal systems). We estimated that the water withdrawal for heating can become as significant as the water withdrawal of thermoelectric power plants in 2015 if only around a tenth of the heating is supplied through ATES. This means that the water use of groundwater will change significantly.

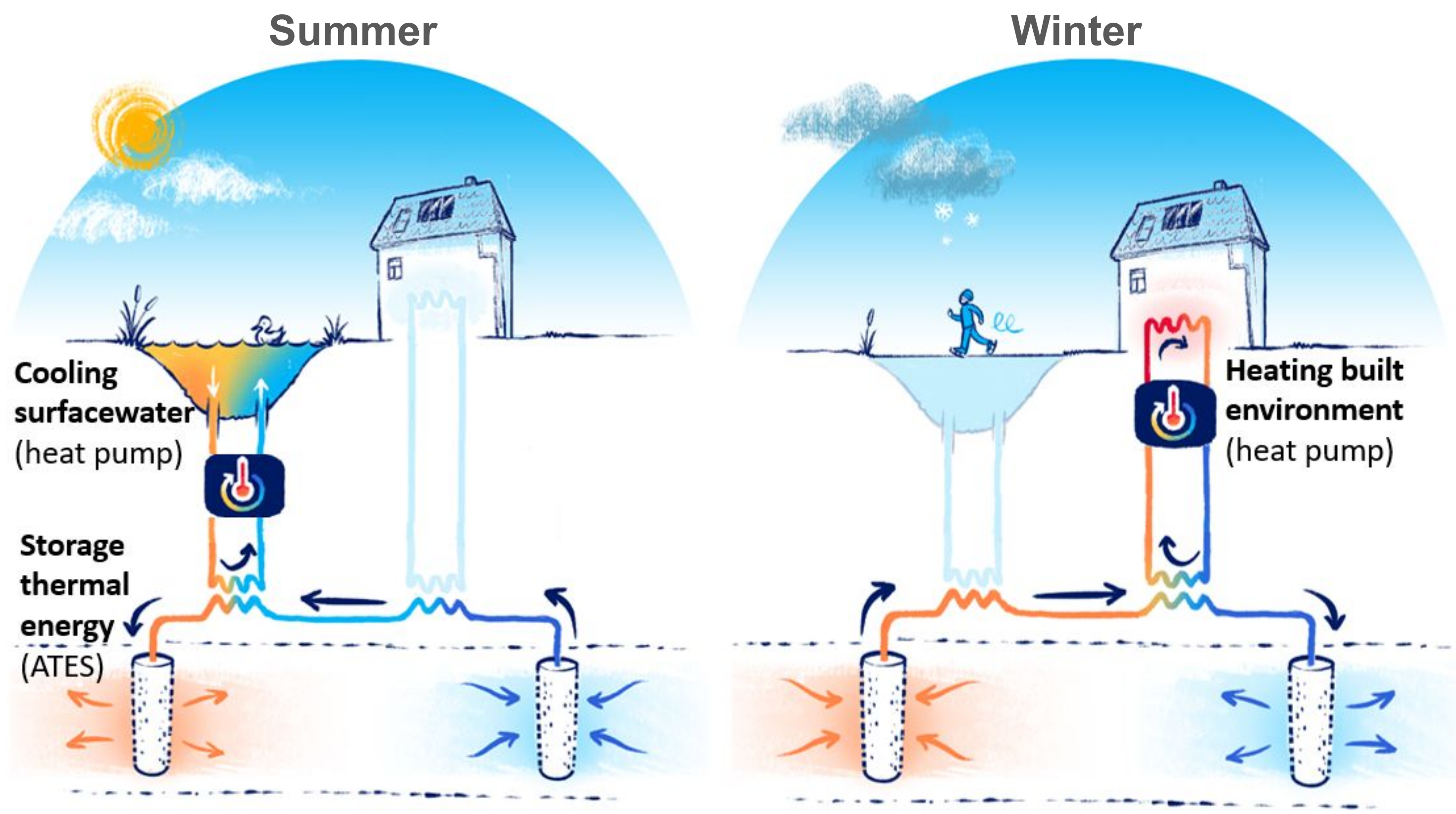
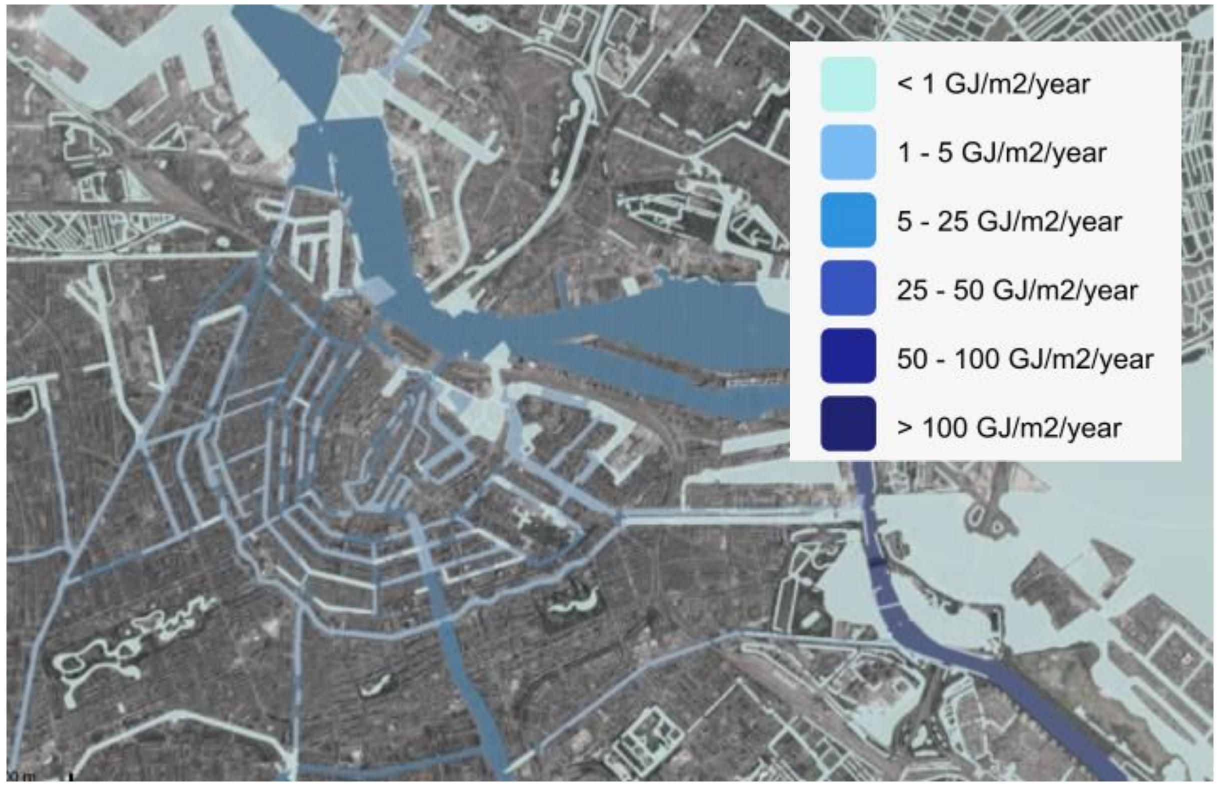


Figure 4: Seasonal thermal energy storage for heating and cooling. Edited picture from Waternet.[10, 11]

Heat from surface water

Hydrothermal energy can be a relevant low-carbon heat source for future low-carbon heating systems in the Netherlands. A conservative estimate is that 12% of the Dutch heat demand can by provided with hydrothermal energy.[12] For Amsterdam, it has even been estimated that 40 to 60%, i.e. up to 15 Petajoules, of the total heat demand can be extracted from surface water (see Figure 5).[13] Although the potential for hydrothermal energy is high in Amsterdam, the amount of possible thermal energy extraction depends on the time of extraction and the size of the water body.

Hydrothermal energy can be applied in two different ways. The thermal energy can be used directly to cool and heat buildings, or it can be stored so that the thermal energy can be used in another season. In the ENLARGE study we looked at hydrothermal energy from water bodies in Amsterdam called ''t IJ', 'Kostverlorenvaart', 'Amstel' and 'Weespertrekvaart'. As a result, hydrothermal energy extraction with seasonal storage appears to be better for the ecology, as it cools the surface water in summer instead of heating it up. This is good for the oxygen content and reduces algae growth and botulism. Because the Kostverlorenvaart is the narrowest canal, and therefore has the least surface area, less thermal energy can be exchanged with the outside air than in the other waters. As a result, the limit of thermal changes within this canal must be carefully considered. **Research and regulations on the ecological impact of heating on surface water use should therefore be a main pillar for a sustainable design of future heating systems in the Netherlands.**



Figuur 5: Potential thermal energy extraction from surface water. Edited figure.[13]

International water footprint

Locally generated energy can have a water footprint on an international scale if water is used to produce energy carriers. Water can for example be used to extract fossil fuels, irrigate energy crops, and produce hydrogen. These energy carriers are traded internationally. Whether the impact of water use is negative depends on where, when and how the energy carriers are made. For example, water use for irrigation is only harmful at places where and during periods in which water scarcity occurs. **The water footprints of energy carriers must be monitored and assessed, in order to limit water scarcity and negative ecological consequences.**

Water footprint of power-to-heat applications

It is important to note that also the energy carrier electricity can have a water footprint at a national and even international scale (see Figure 6). This is because electricity is distributed over a national network and can be generated by internationally sourced fuels. Because electricity can be generated in several ways, integrated assessment models need to be used to estimate the water footprint of electricity.

We argue that the water footprint of electricity will become an important indicator for assessing the water footprint of heat generation.[9] In our research we looked at four energy scenarios for the Netherlands for 2050 and compared these to the energy mix in 2015. The yearly national electricity consumption for P2H applications was estimated to be 2.08 exajoules (EJ) in the 2015 scenario and projected to be between 65.0 and 450 EJ in the 2050 scenarios. **This significant increase means that electricity will become an important energy carrier for heat generation and therefore influences the water footprint of heating.**

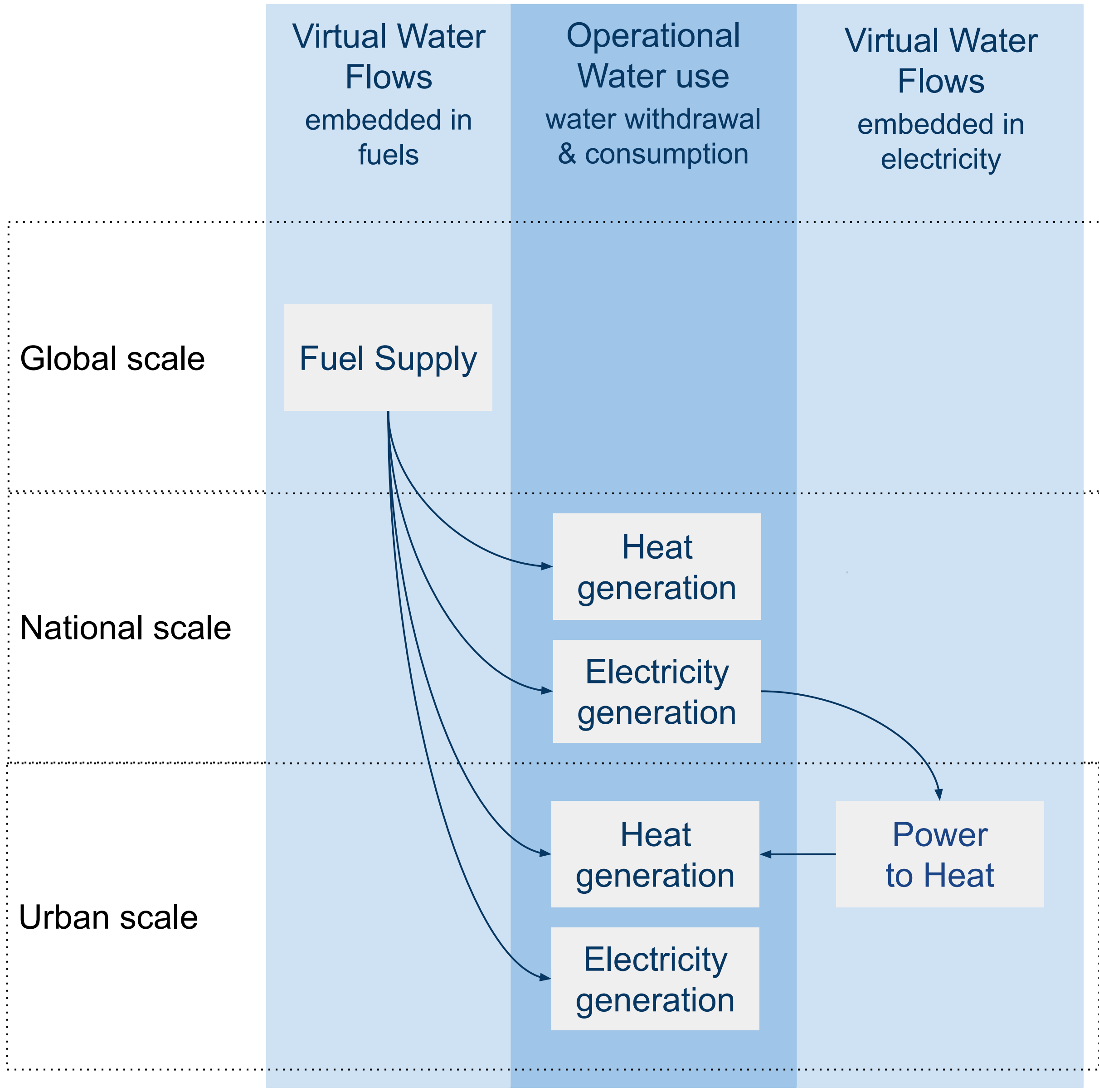


Figure 6: Conceptual model on the Water Footprint of *Power-to-Heat* (P2H) applications. Heat generation at a local scale consumes electricity from the national grid.

Energy justice

It is important that the transition towards renewable heating systems in houses do not exacerbate segregation and marginalization in society. One way to look at inclusivity is to ask critical questions about who is involved in decision-making processes and whether there is a 'fair' energy system. *Energy justice* is a concept used in the scientific literature to analyze justice related to energy systems. **To describe energy justice, three elements are usually considered: distributional, procedural and recognition justice.**[15]

Distributional justice is about the uneven distribution of costs and benefits systems. An example of expressions of claims against an unfair distribution of costs and benefits are protests against a to-be-built thermoelectric cogeneration plant in a municipality in the Amsterdam Metropolitan Area, the municipality of Diemen.[16] Protesters claim that these biomass fuelled plants will cause air pollution, while the benefits for operating those plants are for citizens who are connected to the heat network and international companies operating the plants. Citizens therefore experience the burdens of the system, without necessarily receiving benefits from the system.

The notion of procedural justice is used to analyse whether decision making processes are equitable and non-discriminatory. Dutch reports about the transition towards low-carbon heating systems, such as 'It should not become too adventurous' (Dutch: 'Het moet niet te avontuurlijk worden', show that citizens can feel excluded from decision making processes when deals are made between municipalities and international companies.[6] This can lead to suspicion about underlying interests or people may feel they are not being taken seriously. When people feel they are not taken seriously, or do not feel recognized, we usually speak of recognition (in)justice.

Costs for whom?

Transitioning towards low-carbon heating systems brings questions about distributional justice and affordability of the infrastructure: do we think it is fair that one household pays more for heat than another household? How do we ensure that energy prices do not differ too much between different neighborhoods? And how do we prevent 'energy poverty'? Answering these answers is difficult because different types of measures need to be taken by a variety of stakeholders. Costs for these measures can be paid by citizens, energy collectives, the government and private companies. **To keep future heating systems affordable, careful consideration must be given to who pays the costs and when.**

When assessing affordability of heating systems, it is important to note that infrastructural changes will bring costs on multiple scales. At the neighborhood and city level there are costs for infrastructural changes such as electricity grid reinforcements or heat network placements. Costs for installing heat networks depend on, among other things, the distance to the source, the available space in the subsurface, the scale of the network and the type of material required for the type of heat network. At the building level there are costs for, among other things, insulation, connection to the heat network and monthly bills from energy companies. These costs depend on the type of building, the heating systems used, the chosen market model and the heat demand.

The heat demand of a building depends on the level of insulation. Costs for insulation of old buildings can be high at the building level. On the other hand, non-insulated buildings remain dependent on high temperature heat sources. In the longer term, costs for heat can be higher for non-insulated building stock with much higher demands than for ones retrofitted with insulation.

Social resilience

On the previous pages we explained the concept of energy justice. This concept supports analyzing how our energy system can be set up fairly and equitably. However, problems must not only be identifiable, but society must also be able to tackle them. That is why we describe the concept of social resilience in this policy brief.[17] The notion of resilience is often used in studies to describe the capacity of systems, for example ecosystems, to recover after a disturbance.[17] **Social resilience, on the other hand, is more specific and can be defined as the ability to form new forms of cooperation, rules and institutions to achieve common goals.**

Barriers to participation, innovation and co-creation

Several infrastructural changes and application of innovation are needed to make the built environment free of natural gas. Stimulating new forms of collaboration is important to be able to tackle foreseen and unforeseen challenges of these processes. **New forms of cooperation can be stimulated by looking beyond the existing roles between different sectors.** For example, water companies and water boards can play an important role in the use of hydrothermal energy and UTES because there is a great deal of knowledge about drinking, waste, surface and groundwater.

In order to promote citizen participation, it is important that citizens can sufficiently influence private-public governance arrangements. With infrastructural changes it is important that citizens understand these changes, support them and perhaps even make an active contribution. Participation can not only generate support, but also a forum to express and possibly resolve such concerns of local residents. In various places in the country, some citizens show resistance against high temperature district heating from private parties. One reason for this is the stigma of private parties having a monopoly and that citizens therefore have no insight and influence on decision-making processes. A household that is connected to a district heating network can only choose one provider.

In addition to participation, citizens can also play an even more active role in co-creation projects. An example of this are energy collectives that are organized and managed by a collaboration of citizens, public and sometimes private parties. **To scale up energy collectives and co-creation projects, we notice that there is a need to disseminate success stories and examples of working business models.**[6]

Highlights

Creating sustainable heating infrastructures for the built environment is not just about reducing CO_2 emissions. Sustainable water use and the creation of social inclusion must also be taken into account. We therefore call for the following points to be addressed when drawing up visions and policy:

Low-carbon heating systems

- Insulate buildings and houses to reduce the demand for heat and thus CO_2 emissions. This also makes buildings suitable for low-thermal heating solutions.
- Combine different alternatives such as low-temperature heat networks, hydrothermal energy, power-to-heat applications, and hybrid solutions to make no-regret decisions and achieve the most CO_2 emission reduction possible.

Sustainable water use

- It is expected that water withdrawal for electricity production will decrease when thermal power plants are replaced by wind and solar energy. On the other hand, more water withdrawal is expected for the supply of heat due to an increase in ATES systems and hydrothermal energy extraction. The ecological impact of heat generation should therefore be incorporated in sustainable design of energy systems and regulations.
- If not properly managed, the transition to low-carbon heating systems could exacerbate water stress or be limited by it. Integrated assessments of future heating systems are therefore key for sustainable policies.

Social inclusion

- Analyze the distribution of costs and benefits of energy systems at different scales to get a view on distributional justice.
- Make decision-making processes fair by recognizing and involving multiple parties in the process.
- Look beyond existing roles of sectors to stimulate new partnerships.
- In order to promote participation, it is important that private-public governance arrangements have sufficient participation and supervision with the citizens and the government.
- Encourage knowledge sharing and success stories about collaboration, participation and co-creation projects.

References

1. Ministry of Economic Affairs. 2016. “Energieagenda: naar een CO2-arme energievoorziening.” The Hague: Ministry of Economic Affairs.
2. Segers, Reinoud, Robin Niessink, Robin Van Den Oever, and Marijke Menkveld. 2020. “Warmtemonitor 2019.” Den Haag: CBS.
3. CBS. 2020. “Welke sectoren stoten broeikasgassen”. Web Page visited on 17 November 2020. https://www.cbs.nl/nl-nl/dossier/dossier-broeikasgassen/hoofdcategorieen/welke-sectoren-stoten-broeikasgassen-uit-#:~:text=In%202019%20werd%20van%20de,het%20stoken%20van%20aardgas%20voor
4. Kruit, Katja, and Benno Schepers. 2019. “Functioneel ontwerp LT-warmtenetten gebouwde omgeving.” Delft: CE Delft, commissioned by Planbureau voor de Leefomgeving.
5. Municipality of Amsterdam. 2020. “Transitievisie Warmte Amsterdam.” Amsterdam: Municipality of Amsterdam.
6. Maselis, Ilonka, and Matthijs Hisschemöller. 2018. “‘Het moet niet te avontuurlijk worden’: Een onderzoek naar de institutionele barrières Voor een wijkgebonden warmtevoorziening in Amsterdam”. Rotterdam: DRIFT Institute.
7. CBS, PBL, RIVM, WUR (2020). “Waterwinning en watergebruik in Nederland, 1976-2018 (indicator 0057, version 14, 7 May 2020)”. www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; and Wageningen University and Research, Wageningen.
8. CBS, PBL, RIVM, WUR (2020). “Koelwatergebruik en warmtelozing door elektriciteitscentrales, 1981-2018 (indicator 0021, version 16, 7 May 2020)”. www.clo.nl. Centraal Bureau voor de Statistiek (CBS), Den Haag; PBL Planbureau voor de Leefomgeving, Den Haag; RIVM Rijksinstituut voor Volksgezondheid en Milieu, Bilthoven; and Wageningen University and Research, Wageningen.
9. Kaandorp, C., Van de Giesen, N., and Edo Abraham. 2021. “The water use of heating pathways to 2050: analysis of national and urban energy scenarios”. *Environmental Research Letters, 16(5), p*.055031.
10. Waternet. 2020. “Infopagina omgevingswarmtekaart”. Web page published on 23 September 2020. https://www.waternet.nl/innovatie/co2-reductie/infopagina-omgevingswarmtekaart/
11. Ramaker, M.W.N. 2020. “The Effect of Thermal Energy Recovery on the Ecology of a Small, Slow Flowing Freshwater Ecosystem: A Modelling Approach.” Thesis project Master of Science in Environmental Science of the Open University.
12. STOWA, Ministry of Infrastructure and Water Management, and Union of Waterboards. 2017. “Thermische energie uit oppervlaktewater: kansen voor een aardgasvrij Nederland.”
13. Tim Ruijs. 2019. “Het Amsterdamse Bronnenboek”. Amsterdam: Municipality of Amsterdam. department of Planning and Sustainability.
14. Miedema, Tes. 2020. “The prospects of heat: urban heat modelling as a means for a sustainable and equitable heat transition in the historic centre of Amsterdam”. MSc Master’s thesis part of the Master’s programme Metropolitan Analysis, Design and Engineering.
15. Heffron, Raphael J, and Darren Mccauley. 2014. “Achieving sustainable supply chains through energy justice.” Applied Energy 123: 435–37. https://doi.org/10.1016/j.apenergy.2013.12.034.
16. Zembla. 2019. “Strijden tegen biomassacentrale Diemen: ‘Ons geld wordt verbrand in de oven.’”. Article from television series Zembla. https://www.bnnvara.nl/zembla/artikelen/strijden-tegen-biomassacentrale-diemen-ons-geld-wordt-verbrand-in-de-oven
17. Adger, W. Neil. 2000. “Social and Ecological Resilience: Are They Related?” Progress in Human Geography 24 (3): 347–64. https://journals.sagepub.com/doi/pdf/10.1191/030913200701540465.