TNO-report

TNO Energy Transition Studies
Radarweg 60
1043 NT Amsterdam

www.tno.nl

T +31 88 866 50 10

TNO 2022 P10584

Trend report on sustainability solutions for the built environment

Datum	9 December 2022
Auteur(s)	Vera Rovers, Robin Niessink, Frank Lenzmann, Luuk Engbers, Jorrit Bakker, Renee Kooger
Review	Casper Tigchelaar, Joost Gerdes, Richard van der Gaag
Opdrachtgever	TKI Urban Energy

Summary

TKI Urban Energy (UE) wishes to obtain a clearer picture of the developments in the energy transition in order to understand whether or not the Netherlands is on course to meet the ambitions of the Climate Agreement. TNO has thus prepared trend reports for various sub-programmes within the Multi-Year Mission-Driven Innovation Programmes (MMIPs) of TKI UE. These sub-topics are all of importance to the energy transition in the built environment (Table 1). The trend reports used interviews with two or three experts per topic to investigate current and future developments in relation to the existing housing stock. Each sub-report offers insight into what the interviewed experts believe are the key bottlenecks, developments and boundary conditions when it comes to upscaling. In addition, the impact of potential market developments on the reduction of CO_2 emissions and national costs has also been determined.

The potential market developments are benchmarked against a Baseline – development according to the Climate and Energy Outlook (KEV) for 2030, which is based on the adopted and planned policies (PBL, 2021). In this Baseline scenario, the energy transition in the existing housing stock remains slow: the number of homes in which a Central Heating (CH) boiler is replaced by a heat pump grows from 28,000 to 43,000 by 2030 (for example), and the number of existing homes connected to the district heating grid increases by 84,000. An acceleration of the energy transition in existing buildings is thus essential.

Boundary conditions for upscaling

A stand-out in the interviews is that, in some cases, upscaling benefits from (technological) innovation, but there is often a lack of 1) confidence in and familiarity with the technology and the benefits thereof, 2) a solid business case that offers an incentive to invest and 3) a favourable context for the implementation. Support for sustainability amongst residents is also not so much related to the features of a product or a service but to existing assumptions that residents have and their experiences with the overall process towards sustainable living.

When it comes to heat pumps and low-temperature district heating grids, for example, there remains uncertainty amongst homeowners, housing associations, installers and heat companies as to whether the home can be comfortably heated at low temperature. The fact that these systems can also supply cooling, which will have an important role to play in the future as homes are overheated, is something that is not yet taken into account in considerations. The existence of an industrial approach to the renovation of existing homes remains unknown, which means that demand for it is very limited. In addition, the health and energy-saving benefits of good ventilation are not always recognised, which often means that ventilation after renovation is inadequate. The added value of heat storage is also not recognised in all cases, such as a more even heat supply and to relieve the burden on the electricity grid at peak times using buffering. Pilot projects, demonstrations and proper dissemination of information could help to boost the appeal of unknown solutions.

The lack of legitimate appreciation of the benefits of heat storage also makes it difficult to make a solid business case. There is also something of a skewed business cases here, where the benefits, such as preventing grid reinforcement costs, are not always enjoyed by the party that makes the investment. In the case of energy collectives, creditworthiness can be a bottleneck when it comes to access to financing. In addition, all sub-topics in this report are associated with high initial investment costs that are not expected to fall significantly in the short term. If the benefits are also significant, however, this does not have to mean that a solid business case is impossible, but a lack of familiarity with the technology can make obtaining financing from banks difficult. Recent increases in energy prices have a favourable effect in this regard, as energy savings mean higher energy costs savings as well.

An important contextual factor is that there is a shortage of (skilled) labour to support and upscale the energy transition. Industrial renovation concepts could offer a solution here, but in practice, there is very little demand for them. An important context in heat storage is that each location is unique, not only in terms of the subsurface, but also in terms of policy rules, permit conditions and review frameworks. To upscale energy communities, as another example, a clear legal framework is essential. A clear vision and policy from the government can support the upscaling of various sub-topics covered by this report by creating a favourable context, for instance by means of subsidies for ventilation systems and heat storage, by introducing more consistency to local rules and working methods and by being able to steer and enforce performance requirements.

Where it is clear that innovation is required, this relates to domestic hot water systems, the installation of heat pumps and ventilation systems and the continued development of PV technology and heat storage. Low-temperature heating requires a separate system to supply domestic hot water, for which proper solutions (based on renewable energy) are currently lacking. This is a bottleneck for the energy transition. To accelerate the installation of heat pumps and ventilation systems, plug-and-play methods can play an important role in reducing the labour hours, costs and expertise that are required. Expanding the scope of PV requires innovation in the development of floating panels to prevent corrosion and in the design of PV farms in which agriculture, nature and electricity production can be combined. Innovative storage technologies, including high-temperature storage (HTO), thermochemical storage materials (TCM) and phase-changing materials (PCM), can also offer new solutions for more efficient and more compact heat storage that is more cost effective in the long term.

Impact on the reduction of CO_2 emissions and national costs

The impact of three potential market developments has been determined for a number of sub-topics:

1. Doubling: a doubling of the application of the sub-topic, as assumed in the KEV for 2030.
2. Natural opportunity: the technology is applied when a natural opportunity for replacement occurs.
3. The technical potential: the technology is applied to the maximum. For example: all homes are equipped with a heat pump.

The market developments that were looked at are emphatically not predictions, but show the range of solutions within a sub-topic. In the calculations, a distinction is drawn between the impact of higher market share with the current state of technology and higher market share in the case of innovative application in this topic. For the impact calculations, the study looked only at additional CO_2 emissions reduction and national costs of potential market developments. Consequently, other effects are left out of the picture and are unquantified. The key figures and assumptions that were used are explained in more detail in the sub-reports.

In the KEV, the total direct CO_2 emissions from the housing stock are estimated at 15.8 Mt in 2020 and, after implementation of adopted and intended policy, at 13.8 Mt in 2030, the Baseline. The 'doubling' market development does not give rise to significantly increased CO_2 emissions reduction when compared to the Baseline. Figure 1 indicates the results for the technical potential and demonstrates that, with maximum application of the current technology with solar PV and heat pumps (air and soil), more than 80 per cent of the CO_2 emissions from the KEV estimate for 2030 could already be prevented. Compared with traditional renovation and medium-temperature grids, a far higher reduction in CO_2 emissions can be achieved with innovations such as industrialised renovation and low-temperature district heating grids; innovations in these two topics ultimately result in a reduction of around 80 per cent. The technical potential shows, therefore, that there is still room for energy and CO_2 savings when compared to the KEV.

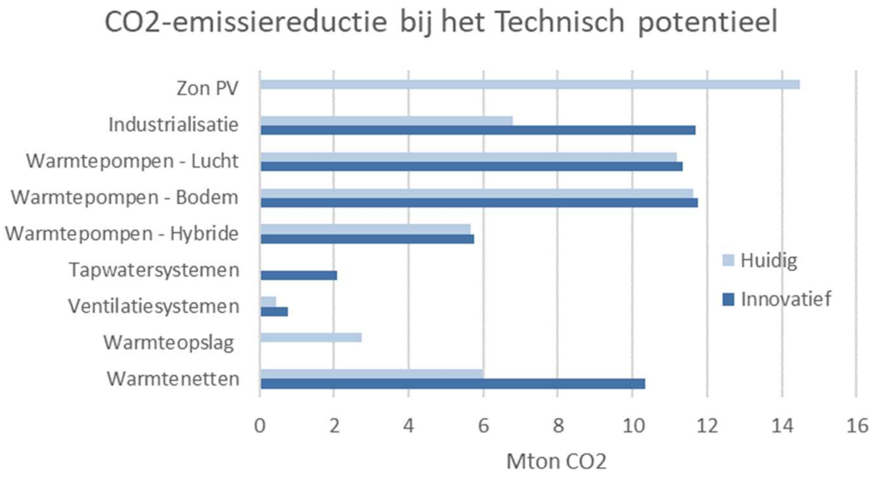


Figure 1 CO_2 emissions reduction of the technical potential of different sub-topics in 2030 when compared to 2020. The emissions reduction of the sub-topics cannot be added together. For the 'innovative technology' of industrialisation, complete building envelope renovation to level 4 of the 'Standard' (RVO, 2022) is assumed, but an industrialised approach is also possible on building components.

Figure 2 provides an overview of the national costs, in other words the balance of costs and benefits for the Netherlands as a whole, for application of the current and innovative variant of the technology when exploiting the full technical potential, determined in respect of the Baseline. The figure shows that an innovation can sometimes give rise to lower costs. In the case of heat pumps, for example, a reduction in costs was assumed on account of cost savings for installation, transport, storage and import. In the case of ventilation, the use of balanced ventilation with heat recovery in existing homes can help to save additional energy in respect of the more commonplace mechanical ventilation system.

In some cases, however, costs are higher. In the case of industrialised renovation rather than the classic approach, it was assumed that a higher insulation level is achieved (level 4 of the 'Standard' rather than level 3), giving rise to higher energy savings as well as higher costs. It must be noted that, if the higher insulation level were to be reached in the traditional manner, the costs would be higher still. The higher costs for low-temperature grids when compared to medium-temperature grids can be attributed to the procurement costs of a separate domestic hot-water system for low-temperature heating. Here too, the higher costs are offset by greater CO_2 savings.

There are also sub-topics with negative costs, i.e. the benefits outweigh the costs, such as with solar panels. Heat storage in an underground layer (known as 'current technology') is associated with negative costs, as additional heat can be used. Heat storage in a tank ('innovative technology') is more expensive and thus results in a positive cost.

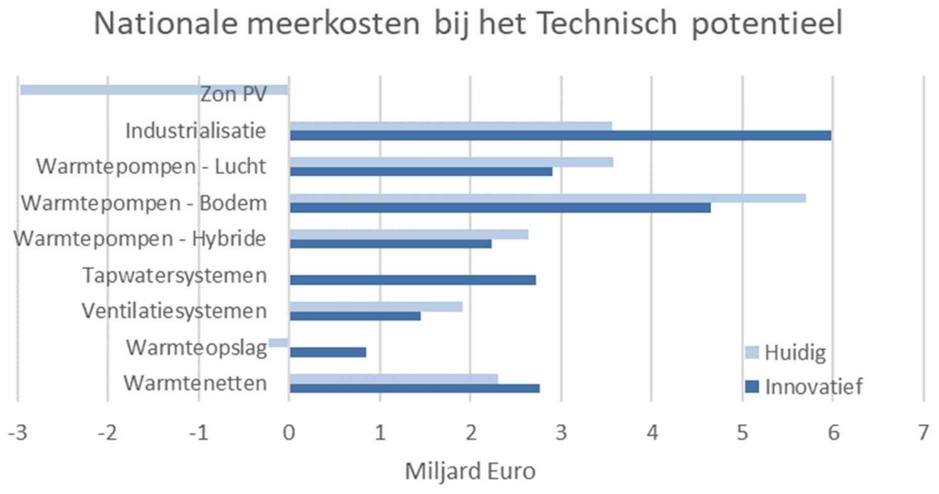


Figure 2 National added costs of the technical potential of different sub-topics in respect of the Baseline in 2030. The costs of the sub-topics cannot be added together. For the 'innovative technology' of industrialisation, complete building envelope renovation to level 4 of the 'Standard' (RVO, 2022) is assumed, but an industrialised approach is also possible on building components.

Inhoudsopgave

Bijlage(n)

Introduction

Reason and question

To achieve the energy transition (more quickly), Top consortium for Knowledge and Innovation Urban Energy (TKI UE) supports innovations. It does this by developing innovation programmes, the Multi-Year Mission-Driven Innovation Programmes (MMIPs), and by providing support to parties during innovation processes. TKI UE is working on two missions: a CO_2-free built environment by 2050 and a fully CO_2-free electricity system by 2050. To this end, TKI UE has formulated four different programmes:

- MMIP2: Renewable electricity generation on land
- MMIP3: Acceleration of energy renovations in the built environment
- MMIP4: Sustainable heat and cold in the built environment (including horticulture)
- MMIP5: Electrification of the energy system in the built environment.

The MMIPs cover several different sub-programmes (see Table 1). TKI UE has formulated Key Performance Indicators (KPIs) or challenges for each sub-programme that are critical to the (accelerated) implementation of the technology or application in that sub-programme.

TKI UE wishes to obtain a clearer picture of the developments in the energy transition in order to know whether or not the Netherlands is on course to meet the ambitions of the Climate Agreement. TKI UE has thus asked TNO to investigate current and future trends for a number of sub-programmes in relation to the existing housing stock and their impact. With this information, it will be able to refine its innovation programme and make adjustments, if necessary.

This document contains several sub-reports, each of which describes developments in a sub-programme. Table 1 provides an overview of all sub-programmes and which of those have been developed in a sub-report. The selection of sub-programmes is based primarily on the market trends formulated by TKI UE. The letters in the table refer to the corresponding sub-reports. Sub-report L is an in-depth topic relating to the labour market that covers multiple MMIPs.

Research question and approach

To get a better picture of developments relating to the sub-programmes, TNO has split the TKI UE question into two parts:

1. What are the developments in a sub-topic?
2. What is the potential impact of upscaling and innovation development of the respective sub-topic?

Table 1 Overview of MMIP TKI UE sub-programmes. The letter in the final column refers to the sub-report where the sub-programme is developed.

Sub-programme	Title	Sub-report
MMIP2: Renewable electricity generation on land		
1	Innovations and broadly applicable technology enablers	
2a	Solar power systems in the built environment	A. Solar PV
2b	Solar power systems in outlying areas	
2c	Wind farms in outlying areas	
2d	Other renewable electricity generation solutions	
MMIP3: Acceleration of energy renovations in the built environment		
3.1	Development of integrated renovation concepts	
3.2	Industrialisation and digitalisation of the renovation process	B. Industrialisation of renovation concepts
3.3	Building owners and users central to energy renovations	C. Drivers
MMIP4: Sustainable heat and cold in the built environment (including horticulture)		
1	Heat pumps	D. Heat pumps
2.1	Output systems	E. Output systems
2.2	Domestic hot water systems	F. Domestic hot water systems
2.3	Ventilation systems	G. Ventilation systems
3	Small-scale heat storage	H. Small-scale heat storage
4	Sustainable heat and cold grids	I. District heating grids
5	Large-scale heat storage	J. Large-scale heat storage
6	Geothermal energy	
7.1-7.4	Ground heat, aquathermal, solar thermal, low-temperature waste heat	
MMIP5: Electrification of the energy system in the built environment		
1	Electrification at building level	
2	Electrification of districts and industrial estates	K. Energy collectives
3	New frameworks for the electricity system of the built environment	
4	Electrical infrastructure in the built environment	
Intersecting topics that transcend MMIPs for the entire Topsector Energy		
	Human Capital Agenda (HCA)	L. Human capital and labour productivity

Developments (qualitative)

The developments and innovations within a sub-topic are described qualitatively on the basis of interviews with two or three experts on the respective topic. These interviews looked at:

- What are the innovations and developments within the sub-programme, and at what stage of development are these innovations?

- To what extent can these innovations contribute to the KPIs formulated within the MMIPs of TKI UE?
- What are boundary conditions for further development?
- What are the anticipated developments in the market, and on what does upscaling depend?

TNO has used this information in the sub-reports, in the ‘Developments in technology’ section, to sketch a picture of ongoing innovation processes on this topic and the way in which they can contribute to the objectives of the TKI UE sub-programme. The ‘Boundary conditions for upscaling’ section summarises how the experts see the developments in the market and the boundary conditions with which they are associated. This qualitative section thus provides insight into what the experts interviewed see as the principal bottlenecks, developments and boundary conditions for achieving upscaling.

Potential impact (quantitative)

This section calculates the potential impact of a sub-topic on CO_2 emissions and national costs for different market developments. TNO has specifically avoided making a forecast for the market development. Development of the market share of sub-topics also depends on external factors that are independent of the innovation itself. The development of energy prices, government policies and the availability of competitive solutions has a major impact on the market penetration of innovations. Consequently, forecasting the market developments of innovations requires a very comprehensive analysis of those external developments. This analysis is not part of the scope of this sub-report. In addition, the role of innovation would be lost in that kind of combined forecast, while the role of technology development is central to the question being asked by TKI UE.

It is important, however, to see the potential an innovation can have and how large the difference is between current development and this potential. TNO makes this clear by sketching out the impact for three predefined, hypothetical market developments. These developments were taken in the same way for each innovation, allowing for a comparison of the potential of different innovations.

1. Doubling: a doubling of the use of the technology as assumed in the KEV for 2030.
2. Natural opportunity: the technology is applied when a natural opportunity for replacement occurs.
3. The technical potential: the technology is applied to the maximum. For example: all homes are equipped with a heat pump.

The potential market developments are reflected in respect of what is referred to as the Baseline – development according to the KEV for 2030, which is based on the adopted and planned policies (PBL, 2021). With this, we are emphatic in not predicting that those presented potentials will also be achieved. The potential market developments do show, however, that a wider range is possible than what is outlined in the KEV and are therefore a thought experiment in relation to the scope of CO_2 reduction and the associated costs or benefits. What part of the potential can be achieved highly depends on the policy choices made and whether the appropriate boundary conditions are thus created. The sub-reports look at which boundary conditions are relevant in this case.

Distinction in target groups

For each sub-topic, we have drawn a distinction between target groups, such as single and multi-family homes and rented and owner-occupied homes. The classification that is relevant depends on the sub-topic.

Impact in the case of higher market share and impact in the case of higher market share + innovation

The impact on CO_2 emissions and on national costs and benefits is calculated for all potential market developments in respect of the KEV. The KEV provides an annual forecast of the impacts of adopted and intended policies on CO_2 emissions. When calculating the impacts, TNO also, to the fullest extent possible, uses the same underlying assumptions and key figures as those used in the KEV. An explanation of these assumptions is provided in the annexes.

The potential impact on CO_2 reduction and the costs and benefits is determined by two factors – an increase in the market share of a sub-topic and an improvement (in efficiency) of the sub-topic itself. Taking heat pumps as an example, the penetration rate of heat pumps in homes may increase, as well as the efficiency of the heat pump itself. To illustrate the impact of both developments separately, two results are provided:

1. Impact of higher market share of the current technology: the impact of the technology or application according to the current state of development if this is implemented on a larger scale. The results are the impact of a higher market penetration rate than is assumed in the KEV.

2. Impact of higher market share with innovative technology: if a new development in the technology has an impact on CO_2 emissions or costs, an impact of this ‘innovative technology’ is also calculated. The scale of application of the technology is kept at the same rate as for the ‘current technology’, but the key figures for calculating the impact are changed.

This report focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. This means that other impacts of higher market share or of an innovation are not taken into consideration but are of course not insignificant.

Reading guide for the sub-reports

The following are the sub-reports for the various technologies. Table 2 provides an overview of all sub-reports. Each sub-report has the same structure, see Figure 3. Following an introduction in which the context and scope are explained, the insights from the interviews are outlined under ‘Developments (in technology)’ and ‘Boundary conditions for upscaling’.

The majority of the sub-reports, except C, H, K and L, also have a quantitative section. This section starts with ‘potential market developments’. It elaborates on the potential market developments for that specific technology and outlines boundary conditions and any innovations that may be required for these market developments. The results of the calculations for CO_2 emissions and national costs are listed in the ‘Impact’ section. The insights from both sections are brought together in the summary. The document concludes with the annexes that provide an overview of the key figures and assumptions that are used for the calculations and the underlying results of the impact calculations.

Table 2 Overview of sub-reports

Sub-report	Sub-topic	Quantitative
A	Solar PV	✓
B	Industrialisation of renovation concepts	✓
C	Drivers and barriers	
D	Heat pumps	✓
E	Output systems	✓
F	Domestic hot water systems	✓
G	Ventilation systems	✓
H	Small-scale heat storage	
I	District heating grids	✓
J	Large-scale heat storage	✓
K	Energy collectives	
I	Human capital and labour productivity	

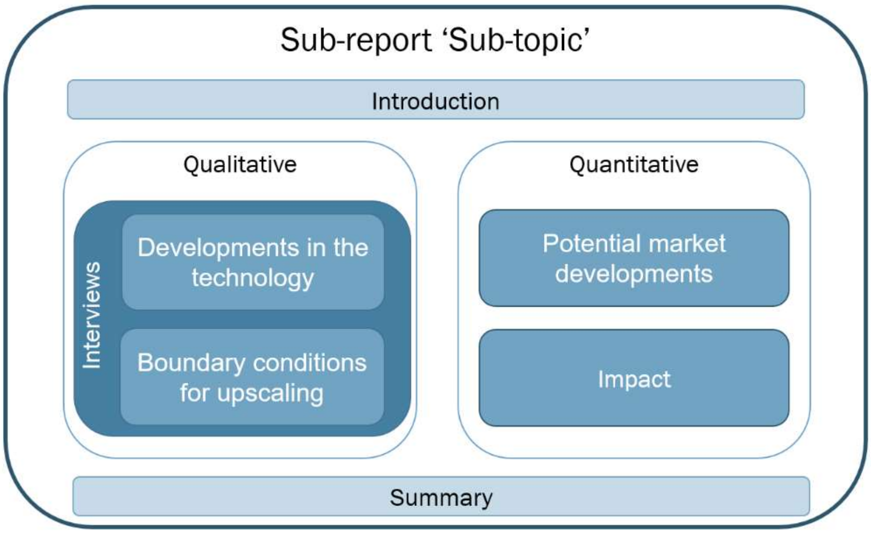


Figure 3 Structure of a sub-report

A. Sub-report – solar PV

Introduction

Context

The use of PV has grown particularly strongly in recent years, especially in the Netherlands. With a current installed capacity of 14.4 GW$_p$ in the Netherlands, PV now supplies more than 11 TWh of electricity per year,[1] which is >10 per cent of all electricity generation in the country. Over the past two years, there has been an annual capacity increase of 3.5 GW$_p$. If this trend continues, the growth will be stronger than in the KEV scenarios, which assume 23 TWh of electricity generation from PV by 2030. As this sub-report explains, PV technology is characterised by considerable potential in terms of further technological improvement in terms of functionality, cost, social aspects and scalability. For this sub-topic, TKI UE has defined the trend:

‘New application areas for PV, increasing the overall area’.

This sub-report will thus give additional attention to new application areas in the built environment and in outlying areas.

Scope

In this sub-report, PV is distinguished in two typologies, ‘PV in the built environment’ (typical scale of a few kW to more than 1 MW) and ‘PV in outlying areas’ (typical scale of a few to tens of MW), for which TKI UE defined the KPIs shown in Table A 1 in 2020 (in ‘KPIs TKI UE 2020’). There developments are designed to open up new application areas in both the built environment and especially in outlying areas, thus increasing the overall area. Specifically, this concerns things like the use of PV not solely on roofs but as part of building façades as well, ideally as an integral part of building elements. Another example is the use of PV on water or as part of infrastructure surfaces (such as noise barriers, for example).

Table A 1 KPIs, PV technology in MMIP2 of TKI UE

KPI
Functionality
Conversion efficiency
Specific efficiency
Service life
Self-consumption
Integration into the energy system
Costs
CAPEX, OPEX, LCOE
Social aspects
Functional integration
Ecological integration
Aesthetics
Safety
Scalability

---

[1] https://opendata.cbs.nl/#/CBS/nl/dataset/82610NED/table?dl=718AF

KPI
Application potential
Potential growth rate of supply chain

Reading guide

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ sections and is based on insights from both the recent literature and interviews with experts. For PV, these experts were Wijnand van Hooff (Holland Solar), Wiep Folkerts and Wim Sinke (both TNO).

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews, the literature and the KEV (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Combined summary of the interviews with Wijnand van Hooff (Holland Solar), Wiep Folkerts (TNO) and Wim Sinke (TNO)

The following is an outline of the current developments and those expected in the near future (up to 2030) in PV technology for each KPI. As the same KPIs largely apply to PV on roofs and PV in outlying areas, there is no distinction in the descriptions between these two system typologies. Where a KPI is specific to one of these two typologies, this is specified. The descriptions also provide substantiated forecasts for future technological features (2030). Where applicable, these are used to quantify the impacts, in combination with the market development scenarios. The developments in the first two KPI categories (functionality, costs) can be forecast with reasonable robustness as they are well within the focus of the R&D landscape of the past 20 years and there is, on this basis, ample knowledge of the learning curves and ‘learning rates[2]’. By contrast, the other two KPI categories largely refer to new areas of R&D, so expectations about developments are much less certain.

---

[2] The ‘learning rate’ indicates the percentage change of a given parameter (e.g. cost, efficiency, etc.), if the cumulative PV power generated doubles.

KPIs for functionality

Conversion efficiency

The conversion efficiency of PV panels has a stable learning rate of between 6 and 7 per cent. With the anticipated growth in the global PV market to 2030 (to around 10 TW_p), it is possible to forecast with reasonable robustness that the current PV panel efficiency will increase from around 20 per cent to around 25 per cent on average (Goldschmidt, Wagner, Pietzecker, & Friedrich, 2021). Developments such as ‘tandem technology’ (whether or not based on perovskite), in which even higher efficiency of around 30 per cent can be anticipated by stacking solar cells with sensitivity in different parts of the light spectrum, may also be commercially available by 2030.

Specific efficiency

The specific efficiency indicates the annual electricity production of a given PV system by power output and is expressed in kWh/kW_p. The specific efficiency depends primarily on the geographical location and any local impediments affecting irradiation (e.g. due to shading). Losses due to shading and other factors can, in some cases, be reduced through improvements to technological configurations, thereby increasing the specific efficiency. Bifacial PV modules (in PV farms), which are used in increasing numbers, also give rise to higher specific efficiency. The European Technology and Innovation Platform (ETIP) assumes a conservative learning rate of 2 per cent (ETIP, 2020), which means that, in the Netherlands, current specific efficiency of around 850 to 900 kWh/kW_p for systems on roofs and 900 to 950 kWh/kW_p for systems in outlying areas (Lensink & Schoots, 2021) is expected to increase further until 2030. This applies to locations that are comparable to those of currently installed PV systems. For more unfavourable locations, however, such as north-facing roofs, east-facing or west-facing façades, etc., which in the future are expected to be used more frequently for building-mounted systems, the specific efficiency is likely to decrease. The average specific efficiency across all locations could, therefore, remain more or less constant, in spite of technological innovation.

Service life

A (practical, not technical) service life/usage duration of around 25 years is currently assumed for PV modules in general (Goldschmidt, Wagner, Pietzecker, & Friedrich, 2021). Although there are expectations that this can be further improved, it is unlikely that this will be achieved before 2030. In view of the expected continuation of increasing system efficiencies and performance, economic incentives to replace older systems with new ones may still remain. In the longer term, it is expected that a service life/usage duration of 30 to 50 years is feasible and realistic (e.g. due to more robust PV module configurations, such as double-glass encapsulation, which is already widely used for PV systems in outlying systems in particular). The current usage duration of PV systems is, in fact, most likely limited to 25 years more by economics than by technological aspects.

Self-consumption (PV in the built environment)

Self-consumption from roof-mounted PV systems, i.e. the proportion of the produced electricity that is directly used locally (rather than being fed into the grid), varies and depends highly on factors such as patterns of electricity use. Private roof-mounted systems, which are often still designed exclusive of electricity storage, achieve average self-consumption rates of around 30 percent (De Heer, Fiorini, & Winters, 2022), while for larger commercial roof-mounted systems, the figure is 60 to 65 per cent (Lensink & Schoots, 2021). In view of the expected increase in system designs that include electricity storage (e.g. in batteries), self-consumption from new systems is expected to increase substantially in the near future (Wirth, 2022).

Integration into the energy system

Generally speaking, this KPI covers all developments relating to PV technology that optimise the impact of PV on the stability, reliability, affordability and security of the energy system as a whole. The overarching concept here is ‘flexibility’, which refers to the option of regulating or controlling demand and/or supply (Sinke, Folkerts, & Weeber, 2021). This also includes solutions for converting solar power into other forms of energy, such as heat or fuels, thereby creating more flexibility through interconnection between the electricity, heat and mobility sectors (sector coupling).

Until just a few years ago, the focus in the installation of PV systems in the Netherlands was primarily on upscaling. There has been strong growth, with the annual increase in capacity currently at a level of 3.5 GW_p and the total installed capacity now at more than 14 GW_p. With PV now accounting for >10 per cent of electricity generation in the Netherlands, aspects that relate to integration into the energy system are becoming ever more important.

A current challenge in this regard is, for instance, the (limited) capacity of the Dutch electricity grids, which often suffer from congestion. Congestion can be eased by using the same grid connection for solar and wind farms (‘cable pooling’), which, thanks to the high degree of complementarity in the generation profiles of solar and wind, allows grid capacity to be used more effectively. The industry associations Holland Solar, NWEA and Energie Samen put together a model agreement for cable pooling in 2021.

KPIs for costs

CAPEX, OPEX, LCOE

In 2021, the CAPEX for systems over 15 kW_p was EUR 500 to EUR 600/kW_p (Lensink & Schoots, 2021). The CAPEX learning rate for PV was relatively constant for decades. For PV modules, it was around 25 per cent, and for PV systems as a whole, including inverters and installation systems, it was around 20 per cent (Goldschmidt, Wagner, Pietzecker, & Friedrich, 2021). There is currently a macroeconomic disruption to markets and supply chains due to the COVID pandemic and the war in Ukraine. Consequently, the cost price for PV (and virtually all other products) is currently on the increase. How the cost price for PV and other products will develop in the years ahead is impossible to predict, but the solid, relatively competitive position of PV is not expected to change. As such, for the sake of forming a picture, the current market disruption is not taken into consideration in this sub-report.

On that basis, and with the global PV capacity expected to be around 10 TW_p by 2030, the decrease from current levels would be around 50 per cent, i.e. to around EUR 250 to EUR 300/kW_p. The decrease in the cost price for PV is the consequence of both economies of scale and innovation (e.g. higher efficiency, reduced use of materials).

Fewer data are available and known about the development of the OPEX, which when compared to the CAPEX has less of an impact on the LCOE. In the framework of this report, it is thus assumed that, for now, the LCOE is more or less consistent with the CAPEX, i.e. by around 50 per cent until 2030 and then falling from the current level of on average EUR 0.04 to EUR 0.08/kWh to EUR 0.02 to EUR 0.04/kWh in the Netherlands (Sinke, Folkerts, & Weeber, 2021).

KPIs for social aspects

Functional integration

Functional integration means advanced designs of PV systems, whereby landscape integration and combinations with agriculture and horticulture (agri PV), infrastructure, etc. are achieved. As of 2022, although there have been some initial successful examples, such as solar carports (e.g. on the car park of the Lowlands festival in Biddinghuizen), functional integration is not yet widely applied, as the concepts are still under development and the first prototype installations are therefore also still relatively expensive. The options are increasingly being explored, however, including as part of demonstration projects. The importance of continued knowledge development in this regard is considerable for several reasons. Firstly, because of the opportunity to tap significant additional spatial potential, which otherwise would not be obvious for PV. Secondly, because functionally integrated designs can resolve social tensions (e.g. between agriculture and energy generation). It is expected that functional integration in the Netherlands will progress one step at a time until 2030, when the development will be market-ready if properly supported by innovation policy.

Ecological integration (outlying areas)

The objective of ecological integration is to eliminate or minimise the risks of impairing nature, ecology (biodiversity, soil quality, etc.) or landscape and the combination of PV and recreation or nature development (Theelen, et al., 2021). In this context, the energy landscape architecture is an important and relatively new area. This field is still under development and will increase in importance up to 2030. In the Netherlands, a certificate is currently being developed to demonstrate ecologically high-quality integration on the basis of gaugeable data about biodiversity and soil quality. This will help to draw more attention to the topic; the certificate could also be used as part of the requirements within project development.

Sustainability

Sustainability and circularity have also only recently gained greater attention from the PV industry now that critical milestones in terms of efficiency and cost have been achieved. Many important developments are still required, including designing PV panels to be more recyclable (‘design for recycling’) and improving raw materials recovery through new recycling technologies (Theelen, et al., 2021). These developments are still in their initial stages. The carbon footprint of PV systems is also expected to decrease further. Current life cycle analyses for representative PV production in China show values of ~1250 kg CO_2-eq/kW_p (Goldschmidt, Wagner, Pietzecker, & Friedrich, 2021). For irradiation conditions such as those in the Netherlands, this amounts to ~55 g CO_2-eq/kWh. With a learning rate of 10 to 14 per cent (Goldschmidt, Wagner, Pietzecker, & Friedrich, 2021), the carbon footprint will decrease to ~850 kg CO_2-eq/kW_p (38 g CO_2-eq/kWh) by 2030. Significant further decreases are feasible, such as through the use of more renewable electricity throughout the production chain (Lenzmann, et al., 2021).

Aesthetics

As with most other KPIs in the social aspects category, options for improving aesthetics have only recently come to attention, as achieving a competitive cost level was more of a priority. The most common systems today are still characterised by relatively little attention to attractive design. The predominant design for PV in the built environment is ‘add-on’ systems on roofs – i.e. PV panels installed on top of existing roofs using mounting structures. For PV in outlying areas, systems often use carrier structures to mount the PV panels, with maximum density and only minimal attention to aesthetic concerns and blending in to the surrounding landscape.

When it comes to aesthetics, therefore, there are many opportunities for improvement. Building-integrated PV (BIPV), i.e. systems where PV panels are integrated into the building envelope and perhaps supplied directly as construction elements, is under development, as are PV panels with different colours. The current share of BIPV is still small, amounting to less than 5 per cent. It is expected that the market share for these more aesthetic PV systems will increase up to 2030.

Safety (PV in the built environment)

Current PV systems can undoubtedly be considered both highly reliable and safe. Nevertheless, a few years ago, there were some concerns about safety on account of a number of rare fire incidents (Sinke, Folkerts, & Weeber, 2021). While these fires were more often related to poor installation quality and incorrect component selection than to the technology itself, it gave cause for further investigation into safety. Ensuring the safety of PV systems is expected to increase in importance even further by 2030.

KPIs for scalability

Potential growth rate of supply chain

PV supply chains, particularly on the upstream side (up to the production of PV panels), are concentrated in Southeast Asia, especially China. With this in mind, there are growing ambitions within the EU for more parts of these supply chains to be relocated to Europe, and in this way to reduce dependence and to help realise economic opportunity. This is also expected to have a positive impact on the robustness and possibly the growth rate of the chains. A key term in this context is ‘mass customisation’, which means a development with which different variants of an end product are produced on a large scale with automation. This development is only in its infancy, and it is not clear what its status will be by 2030.

Application potential

Extensive research has recently been conducted by TKI UE into the application potential of PV in the Netherlands (Van Hooff, Kuijers, Quax, & Witte, 2021). As PV is still a young market in the Netherlands (and outside of it), electricity generation using PV in 2020 was still limited (8 TWh). Despite the dynamic growth achieved in the past two to three years, it is still far below its technical potential. As per recent research by TKI UE, the longer-term spatial potential of 200 TWh is still 25 times higher than PV electricity generation in 2020. As stated in the introduction, the KEV projection of 23 TWh PV by 2030 – in view of the growth rate of 3.5 TWh per year achieved in the past two years – may be too conservative. If this growth rate remains constant until 2030, a total of around 40 TWh can be expected by 2030. Essential to keeping growth constant (or even accelerating it), however, is that favourable development of the individual KPIs is maintained, as explained in the following section.

Boundary conditions for upscaling

Multiple factors are of importance to the upscaling of PV in the Netherlands until 2030. From the perspective of the ever-increasing congestion problems in the electricity grids, the factors concerning integration into the energy system and increasing self-consumption are certainly among the more urgent ones. This means that a much stronger interfacing with flexibility technologies (such as energy storage, conversion and demand-side management) should be integrated into the design of PV systems than is commonplace today. Additionally, reinforcement of the electricity grid is also required.

At the same time, it is essential that public support for PV remains positive. In that regard, it is important to stimulate the developments outlined under the social KPIs, such as functional integration. In the Netherlands in particular, where spatial limitations are more likely to occur than in less densely populated countries, multifunctional use of space is a promising concept for use in further upscaling. Improving recycling and circularity are also important so as not to jeopardise the sustainable value of PV and its public perception.

In addition, it is quite clear that all of the developments outlined in the previous paragraph require innovation, as upscaling industrial production is not enough for continuation of the learning curves referred to. A combination with innovation is required that can be applied in production. For some of the KPIs, the Netherlands has a particularly strong position in the global innovation landscape, thus allowing it to make a more than proportionate contribution to global developments. This primarily concerns the developments of tandem technology, functional and ecological integration and applications on water.

Potential market developments

Description

Baseline

As in the other sub-reports, the Baseline for 2030 is identical to that from the KEV estimate for 2021, which when compared to 2020 equates to a tripling of electricity generation from PV from 8 TWh in 2020 to 23 TWh in 2030. In terms of distribution between homes, non-residential and outlying areas, this report is based on the recent TKI report (Hooff, Kuijers, Quax, & Witte, 2021), which outlines a possible distribution of 37 per cent (8.5 TWh), 41 per cent (9.5 TWh) and 22 per cent (5 TWh) respectively across the three market segments.

Doubling

A doubling of the KEV estimate for 2030 means continued growth of electricity generation from PV to 46 TWh. This would mean that, between 2020 and 2030, there would be average growth of 3.8 TWh per year between 2020 and 2030, which is not significantly more than has been achieved over the past two years, namely ~3 TWh per year. From this perspective, while doubling may seem a sizeable ambition, it does not seem unachievable. Accomplishing this scenario would, however, require the electricity infrastructure to be capable of accommodating the additional quantity of fluctuating electricity generation from PV through grid reinforcement and/or the roll-out of sufficient flexibility (including energy storage and conversion). The same assumption as in the base scenario is made for distribution over the three market segments in this scenario. It is, of course, possible that, in this scenario, different distribution would occur than in the Baseline, as there is currently some social resistance to PV in outlying areas, and this market segment is particularly sensitive to grid congestion. With an emphatic focus on functional integration and adequate electricity infrastructure, however, it is expected that these challenges can be managed.

Technical potential

Rather than the technical potential, this report relies primarily on the findings about spatial potential in the TKI report (Van Hooff, Kuijers, Quax, & Witte, 2021). It is expected that the technical potential will be higher. For the market segment of PV in outlying areas in particular, it can be assumed that the potential is primarily a political/social choice as well. Based on the report mentioned, we assume 82 TWh (homes) and 98 TWh (non-residential) for these two market segments. For outlying areas, an indicative estimate of ≥40 TWh has been determined. The figures continue to use the term ‘technical potential’ in order not to introduce any new terms that deviate from the other sub-reports.

Table A 2 Description of the potential market developments of solar PV, the impact of which has been calculated in this sub-report

Potential market developments for PV	
	Description
Doubling	46 TWh electricity generation from PV in 2030 (homes: 17 TWh, non-residential: 19 TWh, outlying areas: 10 TWh)
Technical potential	At least 200 TWh of electricity generation from PV (homes: 82 TWh, non-residential: 98 TWh, outlying areas ≥40 TWh)
	Boundary conditions
Doubling/technical potential	Integration into the energy system, functional and ecological integration. Availability of adequate electricity infrastructure

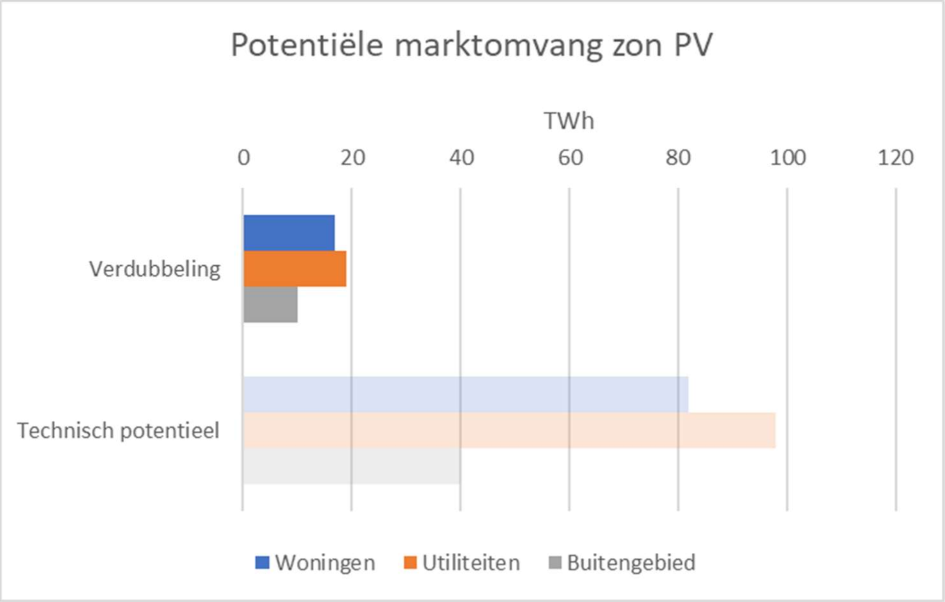


Figure A 1 Potential market developments and technical potential for PV expressed in TWh of electricity generation for the three market segments – homes, non-residential and outlying areas. The potential for PV in outlying areas is uncertain, and the figures show only a minimum potential (see the text for further clarification).

Requisite innovations

As outlined in ‘Boundary conditions for upscaling’, the continuation of a generally high level of innovation in the PV industry is required to enable continued growth, especially if it involves a level of upscaling that goes beyond the level of the KEV (23 TWh in 2030).

In view of the electricity grid congestion problems referred to above, innovations relating to integration into the energy system are of particular importance here. Linking PV with flexibility technologies (such as energy storage, demand-side management, etc.) offers solutions at all levels of the power grid, i.e. at high-voltage, medium-voltage and low-voltage level.

Tapping additional application solutions also requires additional innovations relating to functional and ecological integration, such as agri PV and eco-certificates for PV farms, plus the further development of innovative new application areas, such as BIPV and PV on water. Without innovation in these areas, it is expected that the space and surfaces will not become available for PV.

Impact

This section calculates the potential impact of a sub-topic for different market developments. It focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. This means that other impacts of higher market share or of an innovation are not taken into consideration.

CO_2 emissions reduction

To determine additional CO_2 emissions reduction (when compared to the Baseline), this report assumes that additional generation of electricity from PV will see replacement of fossil generation by 2030. According to the KEV projection, fossil-based electricity production will still be around 40 TWh in 2030, with associated CO_2 emissions of 14.5 Mt (Van Capellen, Wielders, & Scholten, 2021).

The value of 14.5 Mt of CO_2 emissions in this consideration is therefore the upper limit for feasible emissions reduction from PV by 2030, with emissions for PV therefore assumed to be nil.[3] That upper limit would be higher, however, if electricity demand were to increase further still due to electrification of heat and mobility than is currently assumed in the KEV estimate (as this would cause the remaining fossil electricity generation that is to be replaced to increase). On the other hand, that limit would be lower if additional electricity generation beyond the level of the KEV projection in 2030 were to be realised by wind power alongside PV. These two factors relating to the upper limit are not considered here.

In the ‘doubling of the KEV projection’ scenario, there would be 23 TWh of additional electricity generation from PV by 2030 (bringing the total to 46 TWh). The additional reduction in emissions from PV then comes to more than 8 Mt CO_2. The distribution amongst the three market segments – homes, non-residential and outlying areas – in this scenario is 3, 3.4 and 1.8 Mt respectively.

As explained under potential market developments, the technical potential of PV in the Netherlands at around 200 TWh is still many magnitudes higher than 46 TWh. The fossil electricity generation (40 TWh) and related CO_2 emissions (14.5 Mt) remaining by 2030 according to the KEV projection can, therefore, be replaced or eliminated – theoretically at least – by further upscaling of PV. In practice, however, replacing controllable capacity with fluctuating capacity requires radical changes to the electricity system, including the addition of storage capacity.

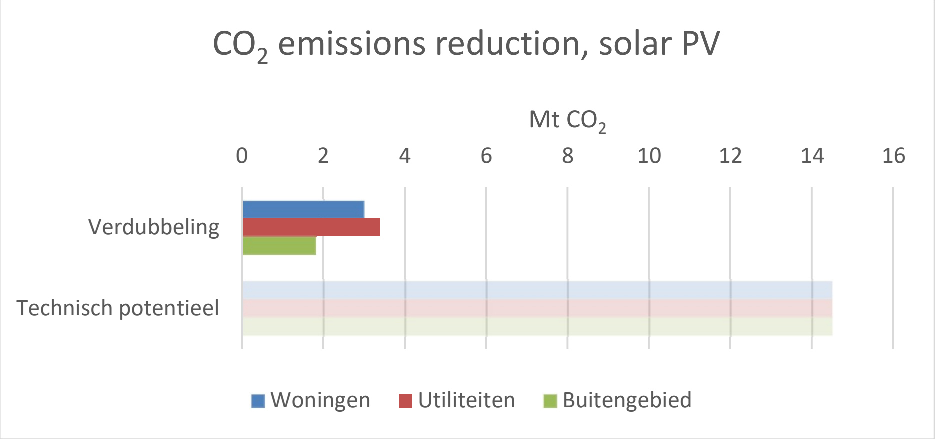


Figure A 2 CO_2 emissions reduction (in Mt CO_2) by replacing fossil electricity generation remaining in 2030 with PV. As that (primarily fossil) generation is limited to 40 TWh, there is also an upper limit for emissions reduction (14.5 Mt). That upper limit is already half-reached in the ‘doubling’ scenario, in which PV electricity production from the three market segments totals 23 TWh.

National costs

By analogy with the previous paragraph on CO_2 emissions, the determination of national costs also assumes the replacement of remaining fossil electricity generation with electricity from PV. To quantify national costs, this report uses the levelised cost of electricity (LCOE), which includes all costs relating to electricity generation and is expressed as EUR/kWh.

---

[3] The lifecycle emissions referred to under the sustainability KPI, which largely arise from the production of PV systems, are not taken into consideration in this analysis (to ensure consistency with the other sub-reports, where chain emissions are also excluded due to lack of available information).

For STEG plants (steam and gas turbine) that predominate within the fossil electricity generation remaining in 2030, the LCOE for 2030 has recently been estimated by CE Delft at EUR 0.069/kWh (Rooijers & Jongsma, 2020). Multiplying by anticipated fossil electricity generation of around 40 TWh, this amounts to total national costs of EUR 2.76 billion. The CLOE of PV anticipated on the basis of learning curves is (in some cases well) below EUR 0.05/kWh in 2030 for all three market segments. As additional electricity generation from PV in 2030 (above the Baseline level) would be provided by PV systems installed gradually between 2020 and 2030, this report assumes the average LCOE for PV between 2020 and 2030. In that case too, the LCOE for all PV market segments remains below EUR 0.06/kWh and is thus a reduction in national costs in any event. The costs for integration into the energy system are not included in this calculation.

With these assumptions, a reduction in national costs of over EUR 0.5 billion is achieved in the ‘doubling of the KEV projection’ by all three market segments together, where distribution across the segments is EUR 0.11 billion for homes, EUR 0.25 billion for non-residential and EUR 0.18 billion for outlying areas. As the simple approach used in this scenario, with an additional 23 TWh of electricity generation from PV, replaces slightly more than half of the fossil electricity generation remaining in 2030 (40 TWh), it can be stated that the maximum achievable reduction in national costs is slightly below EUR 1 billion. This does not take into consideration costs for adjustments to electricity infrastructure or storage. It is also clear that this limit to maximum costs savings will be reached well before the technical potential (~200 TWh) is reached.

The maximum potential reduction in national costs is based on the difference between the LCOE for electricity generation from PV and from STEG plants with a size of 40 TWh in total. In view of the fact that all three market segments are characterised by their own LCOE values (with a decreasing tendency in the order homes > non-residential > outlying areas), there is a maximum possible reduction in national costs for each segment. The corresponding values are around EUR 0.52 billion (homes), EUR 1.04 billion (non-residential) and EUR 1.4 billion (outlying areas). These values cannot be added together (as each value results in an additional electricity production of 40 TWh by itself).

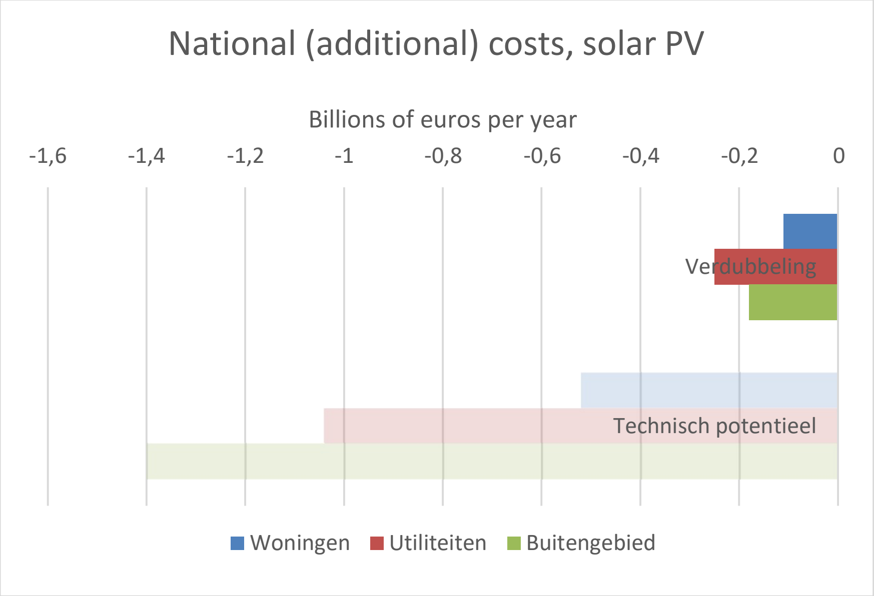


Figure A 3 Reduction in national costs through replacement of fossil electricity generation remaining in 2030 with PV. As that fossil generation is limited to 40 TWh, the reduction in national costs has upper limits of EUR 0.52, 1.04 and 1.4 billion respectively for the three PV market segments. That upper limit, weighted for market segments, is already half-reached in the 'doubling' scenario, in which electricity generation from PV from the three market segments totals 23 TWh.

Summary

Additional use of PV on homes, on non-residential buildings and in outlying areas can make a substantial contribution to the energy transition. If the current dynamic rate of growth (3 TWh per year) continues, this would exceed the market scope of the KEV estimate (23 TWh) in 2030. In addition, recent studies indicate that the spatial potential of PV, (Van Hooff, Kuijers, Quax, & Witte, 2021) at least 200 TWh, is well above the anticipated market scope in 2030. A doubling of the KEV projection would lead to a significant reduction in CO_2 emissions as well as a reduction in national costs, with a scope of over 8 Mt CO_2 and EUR 0.5 billion respectively. The point of departure for these figures is that the additional electricity generation from PV in 2030 will replace the fossil electricity generation remaining in 2030 (40 TWh).

To achieve a market size above the KEV estimate, there is a need, in addition to sufficient labour capacity, for the continuation of an ambitious innovation policy. This innovation policy would need in any event to include barriers to further market development, such as grid congestion and social resistance to PV in outlying areas, as well as the tapping of new application areas (such as PV offshore or agri PV). Innovations required for this include the development of an inverter for integration into the grid, floating panels, functional integration of PV farms in outlying areas and a reduction in the impact of solar panel production and recycling. Moreover, developments relating to mass customisation also offer opportunities for industrial development through (re)stimulation of the European and Dutch PV manufacturing industry.

B. Sub-report – industrialisation of renovation concepts

Introduction

Context

Under the Climate Agreement, the speed at which homes are made more sustainable must be increased to 300,000 homes per year before 2030, and more after that point, so that by 2050, around seven million have been transformed. For MMIP3 ‘Acceleration of energy renovations in the built environment’, TKI UE has defined KPIs to support innovations. Industrialisation of renovation concepts is one of the solutions that could contribute to the requisite upscaling and is the focus of this sub-report. Table B 1 provides an overview of the KPIs and guideline values relating to industrialisation.

Table B 1 KPIs and target values relating to the industrialisation of renovation concepts as defined in the MMIP3 of TKI UE

KPI	Guideline values 2030
Improving sustainability	
CO$_2$ saving	• 3.4 Mt
Energy performance	• 30 to 50 kWh/m^2 primary (homes)
Circularity	• MPG: ≤0.8 EUR/m^2 GFA
Scalability	
Production capacity	• 200,000 homes per year
Intended market volume (number of buildings in NL)	• % of renovations for which an industrial approach can be used
Costs	
Cost price reduction	• 20% to 40% saving on initial investment costs when compared to 2019 and autonomous cost development
Living costs and operating costs	• Living cost or operating cost neutrality
Social aspects	
Appeal	• Increase in conversion rate by >10% (quotes) • Customer satisfaction score ≥7.8 or a Net Promoter Score (NPS) of ≥0 (construction process) • Performance on comfort and indoor environment (improved performance/quality)
Labour productivity	• 30% increase in labour productivity v 2017 • Expansion of labour potential: 481,000 workers v 445,000 in 2018

Scope

TKI UE refers to industrialisation when the emphasis in production processes shifts from manual to machine production. In many cases, this also means a shift of the production process from the construction site to the plant. The development of new renovation concepts themselves is outside the scope of the sub-report; the focus is on industrialisation of the production process to improve the sustainability of the existing housing stock.

Reading guide

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ sections and is based on desk research and the interviews with Marjet Rutten (Constructief) and Huub Keizers (TNO and TKI Bouw en Techniek). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Combined summary of the interviews with Marjet Rutten (Constructief) and Huub Keizers (TNO and TKI Bouw en Techniek)

Many initiatives relating to industrialisation are focused on new buildings. Initial production lines have been established for existing buildings, and a number of innovative projects are under way. For existing buildings, these sustainable industrialisation concepts can be distinguished as follows:

- Renovation of the complete building envelope
- Renovation of one building component, such as external façade insulation or roof renovation (replacement)
- Sub-concepts
- Energy modules (with combined systems)

The experts remarked that these concepts relating to developments in the industrialisation of existing buildings should be considered separately:

Renovation of the complete building envelope: one benefit of this type of renovation is that a higher level of insulation can be achieved than in traditional renovation and that the service life of homes can be extended further. The costs of a renovation of this nature are high, but a truly integrated solution, including heating system, energy generation and ventilation, can still be appealing.

External façade insulation: the costs for external façade insulation are high, and in the case of semi-detached homes, it is only profitable for low energy labels, which means that the market potential is becoming ever smaller as more and more homes are improved. For most private individuals, the costs are too high, and there is a market for housing associations in particular. There may be more potential in the case of apartment buildings. There is also the question of whether such far-reaching insulation of the façade is even necessary. After all, the ‘Standard’ (RVO, 2022) can also be achieved with less interventionist measures.

Roof renovation: roof renovation is more straightforward than façade renovation, as façades have more openings and thus require more customisation.

Sub-concepts: in the case of single-family homes, a sub-concept solution could be a major step towards 2030 – perhaps by offering a combination of replacement of single glazing, internal insulation, draught proofing, ventilation and, if applicable, a heat pump, and marketing it as an industrial product. Industrialisation of sub-concepts dovetails well with an approach of insulating towards the 'Standard'.

Energy modules: this is a concept where the systems can be installed in compact form in the home (plug and play).

KPI – sustainability

An industrial approach has a number of benefits when it comes to sustainability:

- There is far less waste: for new buildings, there is now only one kilogramme of waste per home, rather than 18 m^3, as the procurement of materials can be much better tailored to the size of the element.
- The realisability is also better in general. Standardisation means that materials can be better reused at the end of the product's service life.
- Reduced used of materials and improved recycling have an impact on the Environmental Performance of Buildings. In view of the scale, you can give more attention to the footprint of materials and create a market for the use of new (circular or bio-based) products.
- Fewer transport movements are required, for both material and personnel, which helps to reduce fuel use and (noise) nuisance around the construction site. In terms of personnel, it is because fewer people are needed and because, generally speaking, employees tend to live close to the plant, but not necessarily in the area of the construction site itself.
- Reduction of NO_x, CO_2 and particulate emissions on the construction site.
- As machines can produce customised elements with much greater precision, the different parts fit together more effectively, thus improving the airtightness of building components. As a result, the home has higher energy quality.

The experts interviewed estimate that an industrial renovation will not give rise to renovation that goes beyond what would be achieved with the traditional approach, as clients demand a certain level of insulation and this Rc value (thermal resistance value) is the point of departure. But, if less manpower is needed and the requisite Rc value can be achieved more cost effectively, more homes can be made more sustainable or elevated to a higher insulation level with the same number of labour hours and the same budget.

An industrial approach can have an impact on improving the circularity of the construction and renovation process. There can also be a reduction in CO_2 emissions, as the construction process in the plant requires fewer transport movements and because the energy performance of the home is improved due to better insulation and improved draught proofing***.***

KPI – scalability

1,200 homes were industrially renovated in 2018. When it comes to façade replacement on semi-detached homes, the market has virtually come to a halt right now. The small group of homes for which external façade insulation is of interest are homes with poor energy labels that need to be dealt with well before 2030. There would also appear to be little demand for renovation of whole homes, although the extent is not known. There would appear to be greater potential for roof renovation.

The experts interviewed indicated that construction companies are becoming frustrated by lagging demand. There is also the question of the extent to which industrial renovation comes up during planning. Businesses that invest in renovation will devise a proposal for the approach that will earn them the most in return, while housing associations already have preferred suppliers that do not operate industrially.

There is currently no upscaling, and the market for industrial renovation of complete building envelopes and façades has come to a halt; there is limited demand for roof renovation. The following section looks in more detail at the boundary conditions for upscaling.

KPI – cost price reduction

The largest cost price reduction through industrialisation can be made in the process, as the client and contractor invest fewer hours. Industrial roof renovation could therefore be around 20 to 40 per cent cheaper than the traditional approach. The question is whether the industrialised solution is currently available at less than the price of the traditional approach. In view of the scarcity on the market, parties can ask the same market price they would for traditional renovation.

An impediment to (further) cost reduction is that the capacity of plants is currently far from being exhausted, being around only 24 per cent. A plant requires considerable investment, so if there is low volume, the contribution to capital investment per home is high. In addition, production is currently fragmented (there are already around 35 plants for new buildings), and it is important that output per plant is sufficient.

For industrial roof renovation, a cost price reduction of 20 to 40 per cent may seem realistic, but in that case, the capacity of plants needs to be better utilised.

KPI – appeal

A major benefit of industrial renovation is that it results in less hassle for residents (there are few mistakes, for example) and it is much quicker – renovation can be completed within a week, for example. Renovation of the building envelope also gives the home a new look, thus making it more appealing.

It is essential, however, that consumers have choice, otherwise there is a risk of resistance to the concept. Homeowners being able to make choices based on 3D images would also help and assist in making things more concrete.

Industrial renovation has aspects that make it attractive to homeowners when compared to the traditional method, where offering freedom of choice is an important element when it comes to overcoming resistance to industrialised construction.

KPI – labour productivity

A problem for the traditional approach to renovation is that insufficient numbers of workers are available. With industrialisation, you need less manpower, and processes can be optimised further still on the construction site. With the industrial approach, productivity is much higher than with the traditional approach. As an example, a newly built home built by a fully industrial builder would require around 230 hours, according to the experts interviewed, against 1,200 hours for traditional construction. With the industrial approach, you can save time on proper home visits, during the production process and on completion, as you do not have to return several times to rectify snags. When it comes to industrial systems, you also expect improved labour productivity, as less ‘thinking’ is needed on the construction site itself, and you need fewer system connections. There is the potential for labour productivity to increase even further to 2030 if the volume of industrial construction increases.

A plant requires different specialisms to a construction site, which can make it easier to find and train personnel. As an example, industrialisation offers the option for employees who undertake a single task on a large scale to undergo less broad-ranging training. Expertly trained employees are only really required for critical work, such as setting up a heat pump. In addition, it is important for employees to have digital skills, which must now form part of training programmes.

Working in a plant can also be more attractive, as the work is less physically demanding and weather conditions do not need to be factored in. This also offers opportunities for people with poor job prospects, and for sustainable employability of employees.

TKI UE's guideline value of a 30 per cent improvement in productivity with the industrial approach would appear to be a lower limit; the real figure could be significantly higher. In addition, the pleasant working environment and the less physical and specialised nature of the work can improve the availability of workers.

Boundary conditions for upscaling

Current demand for industrial renovation is limited because awareness of industrial renovation is low and deep renovation comes at high cost. To get this new method of renovation off the ground, therefore, it is essential that contractors purchase differently. Awareness of industrialisation should be raised as an option for renovation. If larger volumes are produced in plants, costs can also be reduced, which in turn would make opting for industrial renovation a more favourable solution. Demand bundling from clients could also help to produce larger volumes, e.g. by getting private individuals to join housing association initiatives. Smaller businesses could also be offered the opportunity to use (flexible) production lines, particularly in sub-concept solutions.

In addition, it is important that attractive solutions are offered, including freedom of choice for the consumer. This means that parties need to offer a flexible approach ('mass customisation').

Potential market developments

In the Climate Agreement, it was agreed that the built environment should be CO_2 neutral by 2050. In the housing stock, CO_2 emissions will need to fall by 2.4 Mt by 2030, which means that more than 50,000 homes will need to be renovated each year, a total of half a million. From (Mulder, Nauta, Klerks, & Donkervoort, 2021), it would appear that the current data are not sufficient to allow the current rate of renovation to be determined.

In this sub-report, potential market developments for the industrialisation of renovation concepts are expressed in terms of the number of renovated homes up to and including 2030, see Figure B 1. Within this, it is assumed that only homes built before 1995 (from after the 1992 Buildings Decree) require renovation, the assumption being that this part of the housing stock is still in its original state and/or has not yet been sufficiently retrofit insulated to be heated free of natural gas. Potential market developments are explained below and outlined briefly in Table B 2.

The interviews showed that industrial renovation concepts would seem more straightforward to apply to apartment buildings than to semi-detached homes. It is also expected that this new type of renovation, particularly external façade insulation, will be carried out primarily by housing associations rather than by individual owner-occupiers, in light of the high costs. With this in mind, we distinguish four different target groups in the market developments:

- single-family – rented
- single-family – owned
- multi-family – rented
- multi-family – owned

Description

Baseline and doubling

The KEV 2021 (PBL, 2021) is in essence the guide for the Baseline of the potential market sub-reports in this report. In the KEV, we do see an increase in the number of individual energy-saving measures, but there are no statements about the number of renovations at home level. As such, we have not included any assumptions about the number of renovated homes for the Baseline. The potential market development 'doubling' has been omitted for the same reason.

Natural opportunity

This approach assumes renovation at a natural opportunity and that the service life of insulation in this case is 50 years. With these figures, 10/50ths of the housing stock would be renovated between 2020 and 2030, which is more than one million homes. Half of this scenario is the pace of sustainability improvement that is the target of the Climate Agreement.

Technical potential

The technical potential is the maximum theoretically achievable potential, whereby it is assumed that all homes built before 1995 will be renovated by 2030. The Climate Agreement aims for 100 per cent sustainability by 2050, 20 years later. This sub-report is thus primarily about demonstrating the impact of so many renovated homes.

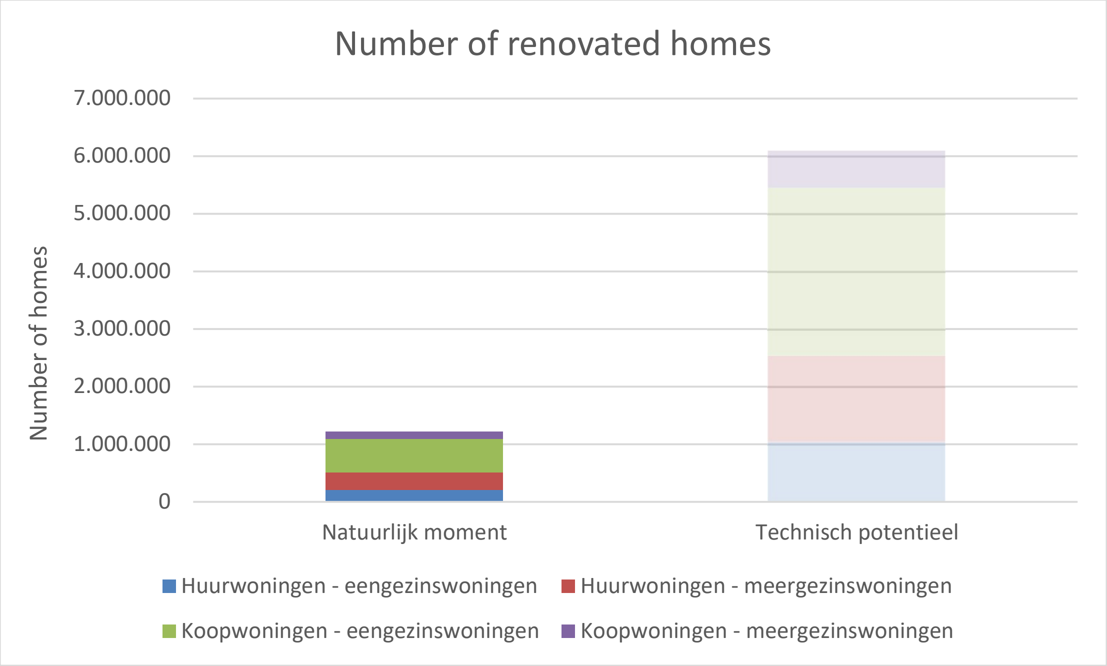
To renovate such a high number of homes, a number of conditions need to be satisfied. Firstly, on the homeowner side: the homeowner must be prepared to make an investment and undergo a renovation, with all the hassle and inconvenience that comes with it. Renovations to the highest level of insulation, level 4 in the 'Standard' (see also 'Impact') cost more than EUR 20,000 for a multi-family home and between EUR 30,000 and 40,000 for a single-family home. Lower investment costs would thus contribute to a more favourable business case. Reducing the inconvenience experienced during renovation could also help to make it more appealing. Traditional renovation involves weeks of construction work in the home. In addition, there needs to be sufficient capacity and materials on the supply side for the renovations to be carried out, in terms of both manpower and expertise.

An industrial renovation approach has the potential to make a positive contribution on all of these aspects – lower costs, more rapid on-site execution and improved labour productivity.

Table B 2 Description of the potential market developments of industrial renovation, the impact of which has been calculated in this sub-report

Potential market developments for industrialisation	
	Description
Doubling	The KEV makes no assumption about the number of renovated homes, so no doubling can be determined.
Natural opportunity	Assuming that the service life of insulation is 50 years, 10/50ths of the housing stock built before 1995 will be renovated between 2020 and 2030.
Technical potential	100 per cent of the homes built before 1995 will have been renovated by 2030
	Boundary conditions
Doubling	N/A
Natural opportunity/technical potential	- Cost price reduction for renovations - A favourable business case and the homeowner's willingness to invest - Solutions that are appealing to the (individual) homeowner - Sufficient labour capacity and expertise - Sufficient construction materials

Figure B 1 The number of renovated homes up to and including 2030 by potential market development and distinguished by target group.



Requisite innovations

Industrialisation can only get off the ground when demand is sufficiently high. Demand will only be sufficiently high if costs fall significantly and the concept is known. Costs will fall only when demand is high. Industrialisation is, therefore, stuck in a deadlock. It is important to break this deadlock for large-scale industrialisation to get off the ground. This means that other actions and measures are needed before innovations. A number of suggestions are made under ‘Boundary conditions for upscaling’ on how the industrialisation of renovation concepts could be increased.

Impact

This section calculates the potential impact of a sub-topic for different market developments. It focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. This means that other impacts of higher market share or of an innovation are not taken into consideration.

When calculating the impact, we draw a distinction between renovation in the ‘traditional’ way – craft work on the construction site – and with an industrial approach. For the traditional approach, we assume that homes are improved to insulation level 3 of the ‘Standard’ (RVO, 2022), which means that the upper limit of commonplace measures is sought. The costs and energy saving (on natural gas) of this renovation for the individual categories have also been derived from the ‘Standard’ (for the figures, see the annex).

In the case of industrial renovation, insulation level 4 of the ‘Standard’, ‘far-reaching measures’, dovetails better as an entire building section is undergoing renovation. Here too, the costs and energy saving have been derived from the ‘Standard’, but the costs have been reduced by 30 per cent. The interviews indicated that, for roof renovations at least, these cost savings can be achieved with an industrial approach. An explanation of these assumptions and figures is provided in the annex.

CO_2 emissions

Renovation with the traditional approach yields a natural gas saving of around 700 m^3/year for a single-family home, and 400 m^3/year for a multi-family home. In the case of industrial renovation, the savings are 1,200 m^3/year and 700 m^3/year respectively. If all homes built before 1995 were renovated with the traditional approach, there would be a saving of 6.8 Mt of CO_2. If, instead, the homes were to be renovated with the industrial approach, the saving would be 11.7 Mt. See Figure B 2 for the different potentials. In the KEV, direct CO_2 emissions from the housing stock are estimated at 15.8 Mt in 2020 and 13.8 Mt in 2030, which means that renovating the housing stock would reduce CO_2 emissions considerably.

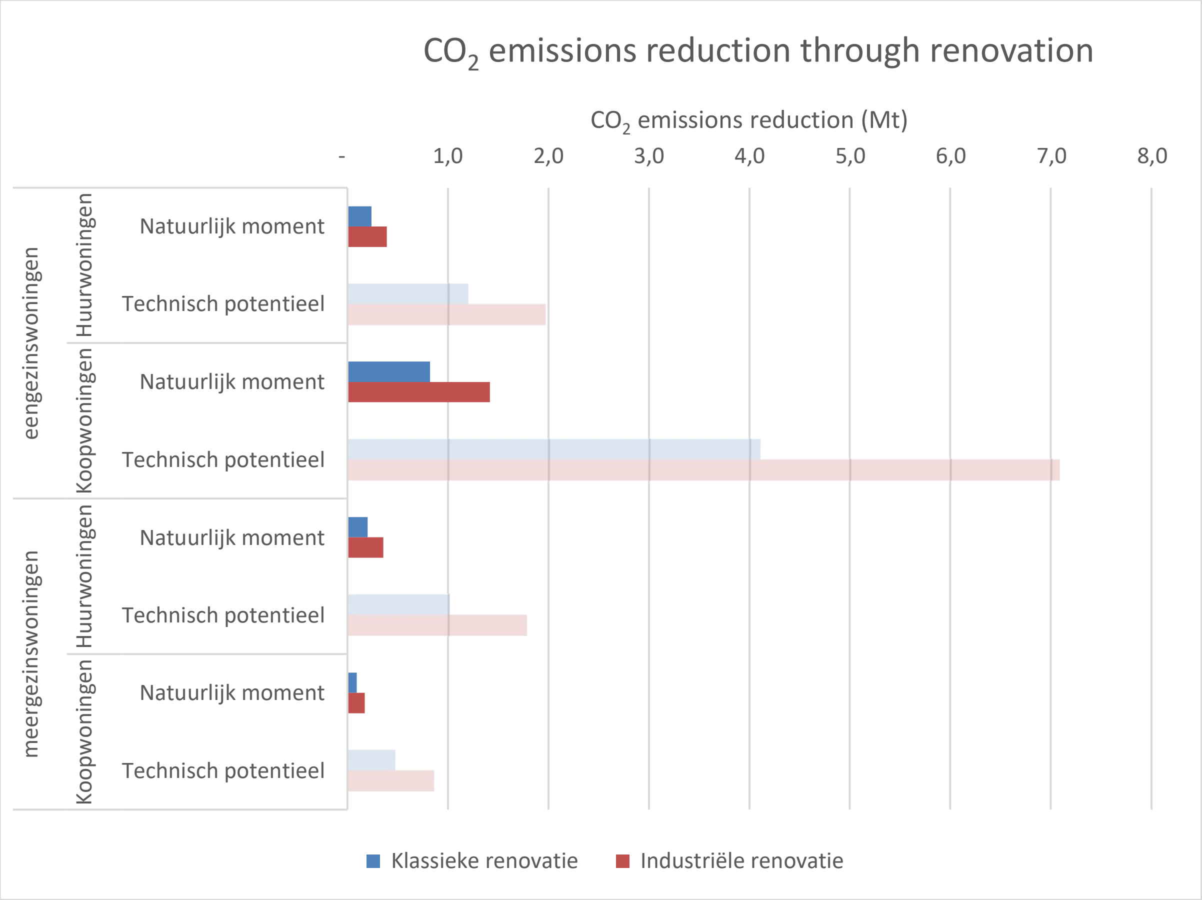


Figure B 2 CO_2 emissions reduction in 2030 as a result of natural gas savings from renovation with the traditional method and the industrial renovation method

National costs

The national costs of the potential market developments are shown in Figure B 3.[4] The national costs comprise the investments required for the renovations and the benefits from the decrease in energy costs due to the natural gas savings. The change in average maintenance costs to the insulation has not been taken into consideration in the calculation of the national costs (here, it is assumed that no periodic maintenance was carried out before renovation and that only limited or no maintenance will be required post-renovation). The annual investment costs are divided over 50 years (the assumed service life of insulation).

The annual investment costs for renovation to level 4 according to the ‘Standard’ are around a factor of three higher than renovation to level 3. No reduction in costs has been assumed for traditional renovation. In the situation of industrial renovations, which is considered an innovation, we assume, on the basis of the interviews, a 30 per cent reduction, as far fewer labour hours are required for renovation. Proportionally, this annual saving on energy costs is around 20 per cent of the annual investment costs (for both the traditional and industrial renovation approach).

The reason for the national costs of industrial renovation being higher when compared to traditional renovation is the higher level of insulation that is assumed for industrial renovation.

---

[4] As the Baseline makes no assumption with regard to renovation, additional national costs are not referred to here (the additional costs when compared to the KEV), only national costs.

As a result, there are higher initial investment costs when compared to traditional renovation, even with a 30 per cent reduction in costs due to industrialisation. The cost savings achieved with industrial renovation are also higher (and the reduction in CO_2 emission is considerably higher), but they only offset the additional investment costs in part when compared to traditional renovation. To compare cost effectiveness, the fairer approach is to compare the costs per tonne of CO_2 avoided – amounting to EUR 360 per tonne in the case of traditional renovation without reduction in costs. The figure for industrial renovation with a 30 per cent reduction in costs included is EUR 470 per tonne of CO_2 avoided (amounting to a 30 per cent difference).

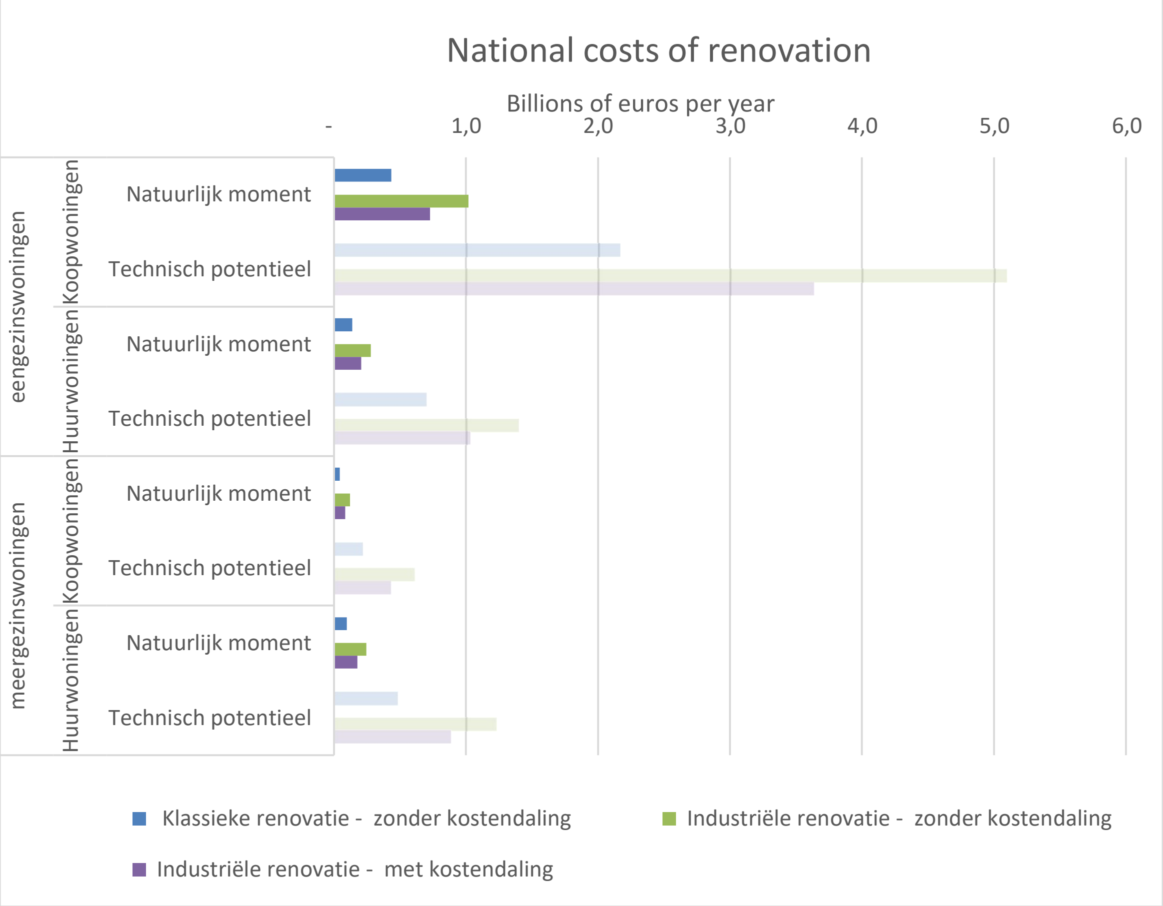


Figure B 3 National costs in 2030 for traditional renovation when compared to industrial renovation (without and with reduction in costs).

Summary

Industrialisation could be a way of producing renovation concepts on a large scale, with less inconvenience, more cost effectively, with greater sustainability and with higher quality. As an example, a 30 per cent reduction in costs for an industrial roof renovation when compared to a renovation with the traditional approach ought to be possible. It should also be possible to achieve a higher level of insulation, thus avoiding additional CO_2 emissions. Corresponding initiatives have been started, but the demand for concepts of this nature is currently stalled. This means that costs per renovation remain high, and investing in industrialisation does not appeal to businesses. In order to accelerate emissions reduction from home renovation, there is a need to stimulate demand for industrially produced renovation concepts. One way of doing this is to offer consumers appealing solutions for renovation concepts, such as with ‘mass customisation’.

Although the first practical cases in the *Stroomversnelling* programme were focused on semi-detached homes, the experts interviewed indicate that apartment buildings may be more suited to industrial concepts. Housing associations in particular can play an important role in creating sufficient demand. Owner-occupied homes may be able to benefit from this demand impulse as well.

C. Sub-report – drivers of and barriers to homeowners

Introduction

Homeowners have an important role to play in the energy transition in the built environment. This sub-topic outlines the drivers of and barriers to homeowners adapting to a natural gas-free home (or a home that is ready to become natural gas free) in the context of a collective solution.

Context

The customer journey to natural gas-free living

Homeowners go through several steps on the path to a home free of natural gas. For this, TNO has developed the ‘customer journey to natural gas-free living’, which encompasses nine steps – Figure C 1 (de Koning, Kooger, Hermans, & Tigchelaar, 2019). The first three steps deal primarily with awareness, where homeowners gather information and form an (initial) opinion about the transition to a natural gas-free home. The fourth to sixth steps are about decision-making. In these steps, homeowners orient and ultimately decide whether or not they wish to make the change to a natural gas-free home. The seventh to ninth steps are about experiences that homeowners have had living in a natural gas-free home. These could include insulation measures as well as renewable energy generation measures or alternatives to heating with natural gas. Research into this customer journey in practice leads to a number of main conclusions:

1. Homeowners go through several steps in the process towards a sustainable/natural gas-free home.
2. Homeowners may discontinue the journey at a particular step for different reasons, preventing them from advancing to the next step.
3. Homeowners are at different steps in the customer journey at different times.
4. Homeowners experience different drivers and barriers in the different steps of the customer journey.

Figure C 1 Customer journey to natural gas-free living

Drivers and barriers relating to attitudes and commitment to the process are most essential to support

The drivers and barriers can also be categorised by type. There are specific drivers and barriers that relate to

- A product or service (this can also be a particular form of financing)

- The characteristics of individual homeowners
- Existing assumptions or attitudes and/or
- Experiences with the process

Although policy development places considerable emphasis on product specifications or homeowner characteristics, in practice, existing assumptions that homeowners have (developed) and their experiences with the overall process towards sustainable living tend to be more important indicators for support for natural gas-free propositions. Some examples of assumptions are: 'natural gas is a clean fuel (barrier)', 'the elite are imposing it upon us (barrier)', 'eventually, we'll have to stop using natural gas anyway (driver)', 'natural gas-free living is safer (driver)'. Some examples of experiences with the process are: 'I feel like I have no choice (barrier)', 'my contribution on what is technically possible in my home is not being taken seriously (barrier)' 'I feel like I am properly listened to (driver)', 'I have confidence in the municipal district team (driver)'.

Support for natural gas-free solutions is thus largely dependent on support for the (local) heat transition. Generally speaking, these drivers and barriers play an important role, whether in terms of connection to a district heating grid, all-electric living or step-by-step towards sustainability. In interviews with homeowners, interviewees rarely, if ever, mentioned the need for more or different types of sustainability measures.
The website of *De energieke gemeente*[5] contains tips, tools and practical examples of how to handle challenges relating to homeowner participation, which, in addition to local authorities, can be of relevance to other interested parties.

Homeowners experience specific drivers and barriers when it comes to connecting to a district heating grid

An investigation carried out by TNO for Enpuls looked at how homeowners can be encouraged to connect to a district heating grid (Kort, de Koning, & Kooger, 2020). Some of the key conclusions from the report are:

- Generally speaking, the level of knowledge amongst homeowners about what a district heating grid actually is and how it works is low.
- Homeowners often have little confidence in heat companies.
- Homeowners value autonomy and independence highly and are resistant to the monopoly position held by heat companies. This means that homeowners tend to be more positive about district heating grids.
- The values of connection and influence play an important role. As such, the way in which and time at which homeowners are involved in the decision-making process largely determines their attitude towards district heating grids.
- The choice of heat source for a heat district affects support amongst homeowners. Homeowners tend to be positive about heat districts with sustainable/renewable sources.

Financing of sustainable measures in homes

In addition to the studies into the drivers and barriers of homeowners in relation to the heat transition, TNO also looked at the perceptions that homeowners have of financing instruments for natural gas-free investments (Hermans, van Lidth, Klösters, Tigchelaar, & Kooger, 2020). Some important insights from this research are:

- People are generally averse to loans. Communication about loaning money needs to focus on the ultimate goal, a sustainable home, rather than the loan itself. This is

---

[5] https://energy.nl/tools/de-energieke-gemeente/

important, as homeowners see this as a useful goal for which they might consider a loan. A loan is viewed as a tool to support homeowners in accomplishing this goal.
- When discussing and offering financing solutions for sustainability housing to older people, take into consideration the different perceptions that this group has about sustainability and financing solutions.
- Offer adequate support and security for low-income and/or low-equity (savings) homeowners so that they have less to be concerned about when it comes to the potential consequences of financing the sustainability of their home.

Reading guide

This sub-report consists of a qualitative section which comprises the ‘Developments’ and ‘Boundary conditions for upscaling’ sections. The ‘Developments’ section outlines current market innovations. The ‘Boundary conditions for upscaling’ section outlines what homeowners need in order to upscale the energy transition. Finally, there is a summary of the trends for this sub-topic.

Developments

There is already plenty of knowledge, and still much knowledge to be acquired, on the topic of resident participation in general. In addition, there are several different market innovations that are either available or under development to support residents, local authorities and energy advisors.

As an example, there are several parties that focus on an overall package for making homes more sustainable, such as Woonduurzaam and De Energiebespaarders. Both of them advise homeowners and reduce the hassle throughout the customer journey when it comes to taking sustainable measures. Another example is Winst uit je Woning, which arranges large-scale purchasing campaigns paired with energy advice. Winst uit je Woning is currently working with TNO to investigate how they can further improve their services.

There are also market players who are responding to the need for participation methods to be upscaled. One such example is TheEarlybirds, which allows homeowners to contribute via a digital environment to things such as making districts free of natural gas or installing a solar farm.

In addition, there are also advisory firms that can actively support local authorities with the transition to sustainable living. Nevertheless, many local authorities continue to struggle with shaping and implementing a solid, area-focused approach.

Finally, Energiepaleis has also worked with institutions including TNO and HU University of Applied Sciences Utrecht to develop a training programme and a tool to support advisors on housing sustainability in both providing technical advice and listening to and understanding the needs of residents. Both are still under development.

In many cases, however, there is too little support in the implementation phase and residents need to investigate and organise a great deal themselves. Moreover, innovations are often underdeveloped, reach only a limited target group or are only specific to certain situations or target groups. This means that market innovations are currently unable to meet all needs.

Boundary conditions for upscaling

The following seven items outline needs to further support residents in the transition to sustainable living:

1. **Upscaling of participation methods**
   Participation processes are often time consuming. What might work for a relatively small group of residents cannot be upscaled to larger districts or local authorities without adaptations. More knowledge is needed of how participation methods can be upscaled without them losing the impact and effectiveness of smaller-scale approaches.
2. **An attractive overall offer for sustainable homes**
   More research is needed into the conditions under which homeowners are prepared to take more rapid and more sustainable measures in one go. Homeowners tend to take one or sometimes two measures at a time. To accelerate the transition, there needs to be greater focus on an offer that is matched to the preferences and needs of residents in different types of homes and coordinated with market opportunities.
3. **More support for homeowners in the implementation phase**
   In many cases, there is support for homeowners in the exploratory phase of the transition to natural gas-free living. As an example, advisors are on hand to coordinate with the homeowner on what measures might be possible and the types of financing that match the situation. Often though, homeowners are left alone once that stage is concluded. The homeowner then has to seek quotes and arrange coordination between the contractor, floor fitter, window fitter, etc. himself. This might discourage homeowners, causing them to discontinue their renovation plans.
4. **More research into the needs of specific target groups**
   People in energy (poverty), non-native speakers of Dutch and younger people are three groups that are not yet sufficiently engaged in the heat transition. More research is needed into what these groups need to allow them and make them willing to take part in the transition. Also, more research is needed into what the role of the local authority, housing association and other relevant parties is in these cases.
5. **More support for local authorities to help them accomplish natural gas-free districts**
   Many municipalities have a (major) shortage of people, time and money to plan and implement natural gas-free districts. More support is needed to allow sufficient time and attention to be paid to a robust process with homeowners.
6. **More support for residents' collectives**
   Residents' collectives can serve as an important partner for local authorities in the planning and implementation of sustainable homes/natural gas-free districts. In many cases, residents' collectives are not yet utilised to their full potential. These collectives also find themselves struggling with their role and keeping the collective together. Improved mutual assistance and coordination between parties is required.
7. **Better interaction between resident, homeowner and installer**
   Installers and advisors can play an important role in the ultimate decision made by a homeowner on whether or not to switch to (for example) a natural gas-free alternative. Homeowners need installers/advisors who, in addition to technical skills, have social skills as well – in many cases, they do not or struggle with the limited time available for home visits, for example. More insight is needed into how the interaction between homeowners and installers/advisors can be improved and what both parties need during that interaction.

Summary

In recent years, in addition to the technical and economic aspects, there has been an increasing amount of attention on the social aspects of the energy and heat transition. This has given rise to increased attention on and interest in facilitating and involving residents in the transition to sustainable living. There is ample research into and practical experience on mapping the preferences and concerns of residents, the opportunities and obstacles faced by local authorities in shaping processes, the emergence of small-scale and large-scale residents' initiatives, energy corporations and commercial organisations that contribute to the development of housing sustainability services. In both the natural gas-free pilots and other municipalities, an increasing number of homes are being made natural gas free, with homeowners becoming increasingly central to the process.

Nevertheless, large-scale home sustainability is yet to be accomplished. We must move towards a situation in which local authorities have the means to implement the transition on a local scale. It is important to start upscaling and fine-tuning the knowledge acquired on resident participation so that: 1) target groups that are difficult to reach also have a voice, 2) there is enough space for a personalised approach but this does not require unrealistic amounts of money and time, 3) there is greater coordination with homeowners, instead of decisions being made without them. Homeowners should be better supported during the implementation phase. At the moment, it often takes homeowners a long time to coordinate between different performing parties, contractors and installers.

We need to move towards a situation in which local authorities are not expected to resolve this major endeavour without (financial) support, time and expertise, and where there is no time or knowledge as to how residents should be involved. In addition, there should be greater awareness of the impact that making a home sustainable/natural gas-free has for homeowners in terms of finance, emotions and time. We have to move past the notion that the biggest hurdle of the heat transition is the decision to more towards natural gas-free living. The government and commercial partners can play a key role in resolving the issues that different groups of homeowners face and speed up to the heat transition.

D. Sub-report – heat pumps

Introduction

Context

The Dutch Climate Agreement aims to make 1.5 million homes natural gas free by 2030. Half of that number is expected to be covered by heat pumps. TKI UE has set out what (further) development of heat pumps is needed to accomplish this ambition and has translated this into KPIs and guideline values for the innovation programme, see Table D 1.

Table D 1 KPIs and guideline values for heat pumps as defined in the MMIP4 of TKI UE. No concrete targets have been set for KPI 7 or KPI 8, but these were included in the list for the purpose of the interviews. (SPF = Seasonal Performance Factor; LTH = low-temperature heating)

System KPI			2019 (reference)	Guideline value 2025	Guideline value 2050
1. Investment costs					50 per cent reduction v 2019
2. Operational costs (EUR/year)					50 per cent reduction v 2019
3. SPF	Air-water	LTH	4	5	5.5
		Domestic hot water	1.75	2	2.5
		Cooling	3	4	4.5
	Water-water	LTH	5.5	6	6.5
		Domestic hot water	2.5-3	3.25	3.5
		Cooling	45	50	55
4. Sound level (dB)					<40/30/27*
5. Global Warming Potential			1430-3950	<150	<5
6. System integration				Smart grid ready	Smart grid friendly
7. Compactness					
8. Installation process					

** outdoors/indoors (traffic space)/indoors (accommodation space)*

Scope

This sub-report focuses primarily on all-electric heat pumps for individual homes in the existing housing stock. Within this, we looked at the heat pump itself (the indoor and/or outdoor unit) and not specifically at developments relating to the heat source, the output system and domestic hot water storage.

Reading guide

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ sections and is based on desk research and interviews with Charles van Geelen (Infinitus and technical secretary of ‘Vereniging Warmtepompen’) and Richard Kemp (TNO). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (2021) (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Summary of the interview with Charles Geelen (Infinitus and technical secretary of ‘Vereniging Warmtepompen’*) and Richard Kemp (TNO)*

Interviewees expect there to be very few fundamental changes to heat pumps up to 2030. The new types of heat pump, such as thermoacoustic and magneto-calorific heat pump, will play a significant role only after 2030. In addition, heat pumps are under development that operate better at higher operating temperatures, such as the CO_2 heat pump (and potentially also the thermoacoustic heat pump). Developments thus far have focused primarily on space heating, but higher-efficiency heat pumps for domestic hot water are now also a focus. Within this, attention is being given to tank design, temperature sensors and ensuring that the water heats up sufficiently but not excessively, as well as to smart control systems that ensure that the water is heated up at a sensible point in time, e.g. when there is surplus electricity or immediately before an expected demand for hot water.

In the following, we look more closely at developments relating to the KPIs that have been formulated by TKI UE in the MMIP. At this point, it is important to note that these KPIs relate not only to the heat pump itself, but to the totality of the system around it as well. When it comes to efficiency, the heat source is important along with the software, user settings, buffer tank and outdoor temperature.

KPI: Investment costs

According to the experts interviewed, the production of heat pumps is almost at full development, and (components of) heat pumps are already mass-produced, which means that any expansion of scale would not be particularly beneficial at this stage. As such, production costs are not expected to fall much farther. There may be room for cost savings in the home installation process, however, which are currently rather high.

Firstly, the installation process can be made more straightforward with, for example, the introduction of plug-and-play systems (see the ‘Installation process’ KPI). In addition, more experience would enable installers to better estimate the risks. At present, installers have built in multiple safeguards to ensure that the risks due to inexperience with this relatively new technology are avoided. Installers also apply the high relative margin on Central Heating (CH) boilers to heat pumps, where much higher absolute amounts are involved. Finally, reductions in transport, storage and import costs remain possible. A rough estimate from the experts interviewed is that a total reduction of around 15 per cent in investment costs is possible as we move towards 2030.

The target of a 50 per cent reduction in investment costs by 2050 does not seem feasible with conventional heat pumps.

KPI: Efficiency

No major steps in terms of technological efficiency improvements in heat pumps themselves are expected in common heat pump types. According to the experts interviewed, there may be scope for an improvement of 5 to 10 per cent.

Important efficiency improvements may still be achieved, however, through more user-friendly and installation-friendly systems and more experience with heat pumps amongst installers and designers. A better adjusted output system and a resident who can manage the characteristics of the heat pump can ensure much improved heat pump performance.

A benefit of the ground-source heat pump in this regard is that, in contrast to air-air or air-water heat pumps, it can keep the COP[6] at a high level, even on the coldest of days. This would make a substantial difference to the grid load of around 2 kW per home. The use of individual ground-source heat pumps in existing buildings often comes up against an objection in that there is a need for part of the garden to be rebuilt (unless installation under a driveway is possible in more spacious areas). Instead of individual ground-source heat systems, a large ground-source heat pump may be installed in existing buildings to serve more homes in a local district heating grid. These small-collective systems (at street level) give rise to less nuisance and cost, but are still underexposed and unknown, possibly because they require cooperation between multiple homeowners, which tends to be more complex.

In addition, new types of heat pump are currently under development, including the thermoacoustic heat pump and the Stirling heat pump, which would appear to maintain a high COP with different sources and output temperatures.

Finally, a lower COP at times of surplus energy is less of a problem than at times of scarcity. A ‘peak load on the electricity grid’ KPI would be an interesting indicator for further investigation. Investigations into this KPI could be carried out for multiple technologies, not only heat pumps. The difference in efficiency at different points in time could also be covered by the operating cost KPI in view of the correlation between energy prices and availability.

The improvement in efficiency ***in the KPI target of 37 per cent for low-temperature heating by air-water heat pumps and 18 per cent for water-water heat pumps with common heat pumps must be primarily accomplished through improved adjustment by the installer, interaction with other systems and more efficient use by the resident.***

KPI: Operating costs

Operating costs depend on efficiency which, as outlined above, is unlikely to change significantly. As such, no major developments are expected in terms of operating costs.

The target of a 50 per cent reduction in operating costs by 2050 does not seem feasible with the intended technical developments in heat pumps.

KPI: Noise

From a technical perspective, it is possible to further reduce the noise from air-source heat pumps, but not all manufacturers choose to do this. Heat pumps designed with attention to noise are now around 2 to 3 dB quieter than they were five years ago. The noise is caused by

---

[6] Coefficient of Performance (COP) is an indication of the ratio of heat supplied relative to consumption. A high COP means that a heat pump delivers lots of heat with low consumption.

the compressor and the fan. Noise from the compressor can be reduced with effective vibration damping and insulation. In the case of the fan, a good deal can still be gained through good blade design and diffuse distribution of the airflow. In addition, larger fans produce less noise, so the desired/intuitive trend in the direction of more compact heat pumps naturally conflicts with this KPI. Finally, soundproofing cabinets are available for heat pumps, although they tend to be quite expensive (EUR 1000 or more).

Technically speaking, it is possible to make heat pumps much quieter and thereby achieve the targets.

KPI: Global Warming Potential (GWP)

The Global Warming Potential (GWP) is an indication of the extent to which a greenhouse gas in the atmosphere contributes to climate change. There has recently been a major shift from use of R410 as a refrigerant to R32 – R32 has a lower GWP and is now used widely. There is a trade-off between the GWP, the toxicity and the flammability of refrigerants, but in general, the risk of leaks is considered acceptable for domestic use.

There are currently a variety of developments in the field of natural refrigerants. As an example, the use of propane is on the rise, although it tends to be used mostly in outdoor units. In view of its flammability, a maximum of 150 grammes is now permitted indoors, which is insufficient for use as a refrigerant. To encourage the use of natural refrigerants, the permitted quantity of propane should be increased to around 1000 grammes.

Other natural refrigerants also have their limitations, including ammonia, which due to its toxicity is unlikely to be used domestically, and CO_2, which requires higher pressure and, in turn, heavier components and piping, thereby increasing the price.

Synthetic refrigerants with a lower GWP are also under development, but the disadvantage of these is that conversion may occur in the atmosphere, leading to a very high GWP (perhaps 10,000 times as high).

Generally speaking, it is expected that, by 2030, propane will be the most frequently used medium in monoblocs,[7] and R32 in split units.

Experts anticipate that primarily propane (GWP 3) will be used in monoblocs from 2030 onwards, helping to achieve the 2050 GWP<5 target sooner. For split units, however, R32 (GWP 675) will continue to be used – temporarily – which is higher than TKI UE's target value for 2025 of GWP <150.

KPI: System integration

New heat pumps from reputable manufacturers are almost all 'smart grid-ready'. This means that the use of heat pumps can be matched to the current load on the grid. As a result, peak load on the grid can be reduced, minimising the need for investment in grid reinforcement. The substantive challenge lies in standardisation of communication protocols between the heat pump and the grid operator. The organisational challenge is in who will take the lead: at macro level, many expect grid operators/TenneT to take the initiative. At micro level (within an individual home), there are already a number of options for household appliances to communicate with one another – even though the technology is at an early stage of

---

[7] In the case of a monobloc, all components are integrated into a single (outdoor) unit.

development – to help even out the load on the grid. In addition, smart heat pumps can shift heat production to times when electricity demand on the grid is low.

The target for smart grid-ready heat pumps by 2025 has already been satisfied. These heat pumps are not yet used as such, however.

KPI: Compactness

Heat pumps are already being designed to be compact, and the expectation is that they cannot be made much more compact without comprising capacity/output. If the capacity can be reduced through better home insulation, heat pumps could be made even smaller.

It must be noted that larger heat pumps have better efficiency, primarily because of the large heat exchanger, and that they generate less noise because of the larger fan. The outdoor unit (of the air-source heat pump) would thus need to be as large as possible. With this in mind, there is an opposing interest between compactness on the one hand and efficiency and noise reduction on the other.

It is not expected that heat pumps will be designed to be much more compact than they already are. In actual fact, the outdoor unit should be as large as possible.

KPI: Installation process

To simplify the installation process, developments are required in relation to plug and play and familiarity with the heat pump. These could include hydraulic connections and standardised hydraulic modules, a standardised printed circuit board, pre-programmed control settings, systems that simplify checks during installation and the ability to quickly connect pipework (without the need for soldering, for example). In addition, more straightforward installation also contributes to improved quality of the system and its operation.

Those interviewed have confirmed the importance of simplifying installation work

Boundary conditions for upscaling

The technology of heat pumps is in itself sufficiently developed to be applied on a large scale, and there is an appropriate heat pump for almost all domestic situations. A small amount of insulation is often enough, possibly supplemented by fan radiators. In the event of doubt, a hybrid heat pump may be installed, which is flexible and can easily use half the standard quantity of gas, or less, in a well-insulated home. The supply of heat pumps does not need to pose a problem either, as manufacturers are capable of producing them. At present, however, there may be supply problems due to material and chip shortages or logistics problems.

Increasing gas prices are currently the key driver for installing heat pumps, which means that the level of investment is an important aspect in the considerations of the homeowner.

At present, the most significant obstacles to upscaling heat pumps are barriers to installation. The two main reasons are:
- The costs of installation are too high (see also ‘Investment costs KPI’)
- There are too few qualified installers

Plug-and-play systems for heat pumps are thus crucial. These help to simplify the installation process, which can help to reduce costs and the labour force needed.

Integration into existing buildings is a higher risk for installers than using heat pumps in new buildings. In the latter, there is greater control over what will be built and what is to be expected. In the case of existing buildings, measurements are possible beforehand, but there is a question of whether things will work as expected afterwards – will the home get warm, will the installer need to return? As such, it is important to give homeowners certainty and to ensure that better guidelines are in place to help overcome problems.

There is a need for a trade-off between the extent of insulation and the systems. Do you want to install far-reaching insulation so that you can install a low-capacity heat pump, or is it better to install a heat pump with higher capacity or a high-temperature or hybrid heat pump? For each (type of) home, it is important to determine the optimal solution of what works well from an energy perspective, delivers reliably and is not excessively expensive. As it is, 60 per cent of homes are already LT-ready according to a study by WarmingUP (Pothof, Vreeken, & Meerkerk, 2022).

In addition, a proposal for new legislation relating to legionella may have consequences for heat pumps for domestic hot water (see the ‘Domestic hot water systems’ sub-report). This legislation would mean that the temperature in the entire storage cylinder would need to be maintained at a minimum of 60 degrees continuously. That would mean a lower COP and, potentially, additional electric firing if the heat pump cannot manage it by itself.

Finally, the local impact of the use of all-electric heat pumps should also be considered. If an entire district switches over to all-electric (and has an electric car and solar panels), it will lead to the electricity grid being overloaded in the absence of measures to spread out the load.

Potential market developments

The potential market developments for heat pumps are outlined below, with an explanation of the boundary conditions for accomplishing this development and the innovations needed to that end.

Here, we look at three types of heat pumps – the all-electric air-water heat pump, the all-electric ground-source heat pump and a hybrid heat pump, comprising an air-water heat pump and CH boiler. In the market developments for heat pumps, we draw a distinction between single-family homes and multi-family homes, as the interviews suggested that ground-source heat pumps are more suitable for collective systems and are thus easy to install in existing buildings.

Description

Baseline

We benchmark the potentials against the Baseline scenario, which we base on the KEV 2021 (PBL, 2021) which shows how many homes will have heat pumps in 2030, both existing buildings and new buildings. To determine the extent to which existing homes have had a CH boiler replaced by a heat pump, we looked at those built before 1995. By 2020, these replacements had affected around 28,000 homes. In the KEV, the number of existing homes in which a heat pump is installed to replace a CH boiler increases to around 43,000 by 2030. This is thus a very limited share of the entire housing stock, as the expectation is that, without additional policy in place, heat pumps will be primarily installed in newly built homes and less frequently in existing homes. There are only indications of the number of hybrid systems out of the total number of heat pump systems, so there is no distinction between all-electric systems and hybrid systems for the Baseline. According to statistics on heating systems from Statistics Netherlands, 0.8 per cent of the total number of homes in the Netherlands used an electric heating system with relatively ‘low’ or ‘high’ gas consumption in 2021 (CBS, 2022). The same table shows that 2.4 per cent of homes have electric heating. Based on this, it follows that around one third of homes have hybrid (electric) heating. This share is indicative, as it relates to homes with an electric heat pump or other form of electric heating.

Doubling

Another potential market development looked at here is the doubling of the speed at which CH boilers are replaced by heat pumps when compared to the Baseline. For this development, we take the number of existing homes in the Baseline scenario in which a CH boiler has been replaced by an all-electric heat pump between 2020 and 2030 and then double it.

To accomplish a doubling when compared to the KEV, we believe that, based on insights from the interviews, there are a number of conditions. The first is a more favourable cost-benefit ratio for homeowners. Heat pumps are more expensive than CH boilers. In addition, additional costs are usually incurred, such as those for retrofit insulation and low-temperature heating. This may discourage switching. A more favourable cost-benefit ratio when compared to CH boilers can be achieved through cost reductions for heat pumps, grants, a reduction in the electricity price and/or an increase in the gas price. While writing this sub-report, gas and electricity prices rose considerably, thus accelerating the demand for heat pumps. It is unclear for how long natural gas prices will remain so high. Even with a more favourable cost-benefit ratio, homeowners will need to be prepared to make an investment –homeowners will need to have money available or be prepared to borrow it. In addition, the heat pump must also offer an appealing alternative for the owner when compared to a CH boiler, and they will also need to be confident of its operability in the home. Finally, a sufficient number of installers must be available.

Natural opportunity

For this potential development, CH boilers will be replaced by heat pumps at a natural opportunity. Based on a service life of a CH boiler of 15 years, around 10/15th of CH boilers will need to be replaced in the decade between 2020 and 2030. For the hybrid heat pump, this development has been incorporated into policy – with effect from 2026, it is expected that switching to a hybrid heat pump (or another sustainable alternative) when replacing a CH boiler[8] will be compulsory.

When it comes to doubling, this potential market development represents a very rapid increase in the number of heat pumps. This will put pressure on installation capacity, which is already limited. With this in mind, to replace CH boilers at natural points in time, the number of (qualified) workers will need to increase, installation will need to be simplified so that less expertise is needed and more people can undertake it, and installation times will need to be shortened.

Technical potential

---

[8] https://www.rijksoverheid.nl/actueel/nieuws/2022/05/17/hybride-warmtepomp-de-nieuwe-standaard-vanaf-2026

The last potential market development assumes that 100 per cent of all homes that still have a CH boiler according to the KEV will have switched to a heat pump by 2030. The potential in which 100 per cent of homes that still have a CH boiler are fitted with a heat pump is known as the 'technical potential'. The boundary conditions for complete replacement are the same as for 'replacement at a natural opportunity'. Table D 2 provides a brief description of potential market developments.

Table D 2 Description of the potential market developments of heat pumps, the impact of which has been calculated in this sub-report

Potential market developments for all-electric heat pumps	
	Description
Baseline	The number of CH boilers in existing homes that are replaced by an all-electric or hybrid heat pump based on adopted and intended policies
Doubling	Doubling of the number of existing homes in which a CH boiler is replaced with an all-electric or hybrid heat pump
Natural opportunity	In homes, the CH boiler is replaced by an all-electric or hybrid heat pump at a natural opportunity
Technical potential	In 100 per cent of homes that still have a CH boiler in 2030 according to the KEV, the boiler will be replaced by an all-electric or hybrid heat pump
	Boundary conditions
Baseline	- Adopted and intended policies are applied
Doubling	- High gas prices/low cost of heat pump - Interest, willingness to invest and confidence of owner
Natural opportunity/ technical potential	- High gas prices/low cost of heat pump - Interest, willingness to invest and confidence of owner - Sufficient installation capacity and expertise

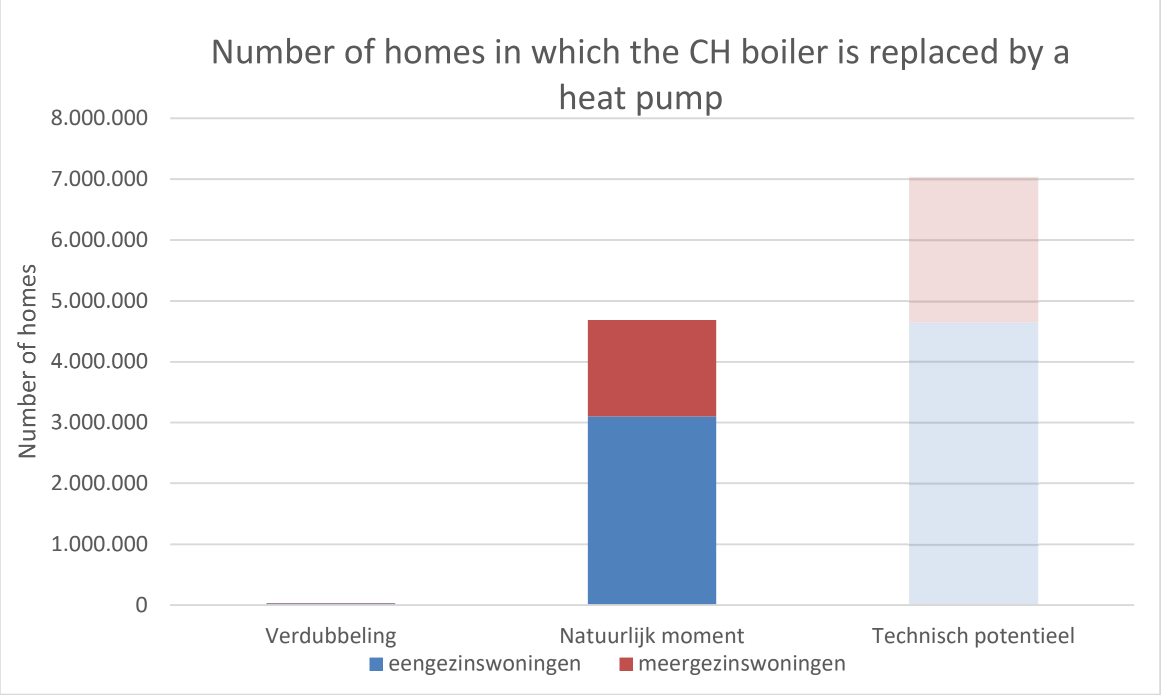


Figure D 1 Number of homes relative to the Baseline in which a CH boiler is replaced by a heat pump in 2030 under the various potential market developments.

Requisite innovations

Heat pumps are relatively expensive to purchase and take longer to install when compared to a CH boiler, which means that more installers (labour hours) are required, making installation more expensive. Upscaling the replacement of CH boilers with heat pumps thus places additional pressure on available installer capacity. An innovation, such as a plug-and play-installation that simplifies and speeds up the installation process, could be a solution to this particular obstacle. This could help to lower the labour hours and expertise required, thus eliminating key barriers to upscaling.

Impact

This section calculates the potential impact of a sub-topic for different market developments. It focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. Other effects of a higher market share or innovation, such as quieter and more compact systems and more rapid installation (i.e. shorter delays), are thus not taken into consideration.

Heat pumps now form only a small part of the market for installations in existing buildings. Also, the 2021 KEV does not expect their use increasing rapidly under the policy in force at the time. As a consequence, a doubling when compared to the Baseline will have only very limited effect (around 30,000 homes) on the growth of the total number of heat pumps. A more ambitious approach is needed for large-scale replacement of CH boilers with heat pumps. The following looks at the potential effects on CO_2 emissions and national costs. The underlying tables with detailed results can be found in the annex.

CO_2 emissions

When a CH boiler is replaced by an all-electric heat pump, natural gas is no longer used for space heating or domestic hot water. In the case of a hybrid heating system in existing homes, it is assumed that the proportion of the heat demand for space heating and domestic hot water met by the heat pump is half. The technical potential for all-electric heat pumps comes to a potential reduction in emissions of 13.3 Mt CO_2. By way of comparison, total direct CO_2 emissions (temperature-adjusted) from the housing stock in the Baseline scenario in the KEV are estimated at 15.8 Mt in 2020 and at 13.8 Mt in 2030 (PBL, 2021). This implies that residual emissions remain. The reason for CO_2 emissions not reaching nil is that, in this market development, only those homes that still have a CH boiler in the Baseline scenario in 2030 replace the boiler with a heat pump. Homes that are heated with a different technology (such as a district heating grid, hybrid heat pump) will continue to produce CO_2 emissions. The technical potential for hybrid heat pumps comes to a potential reduction in emissions of 6.7 Mt CO_2.

The use of heat pumps leads to an increase in indirect CO_2 emissions in the electricity sector. The emission factor for electricity generation decreases sharply in the KEV 2021 estimate for 2030 (see General figures in the appendix), however. For the technical potential in the case of all-electric air-source heat pumps, this is an increase of 2.1 Mt, giving rise to a net reduction (reduction in direct emissions – increase in indirect emissions) of 11.2 Mt. In view of the higher system efficiency of ground-source heat pumps, less electricity is required, which leads to lower indirect CO_2 emissions (1.6 Mt), bringing the total reduction for ground-source heat pumps to a total of 11.6 Mt. In the case of hybrid heat pumps, electricity use leads to 1 Mt of indirect CO_2 emissions, bringing the CO_2 savings to 5.7 Mt. Figure D 2 gives the net emissions reduction, distinguished between single and multi-family homes.

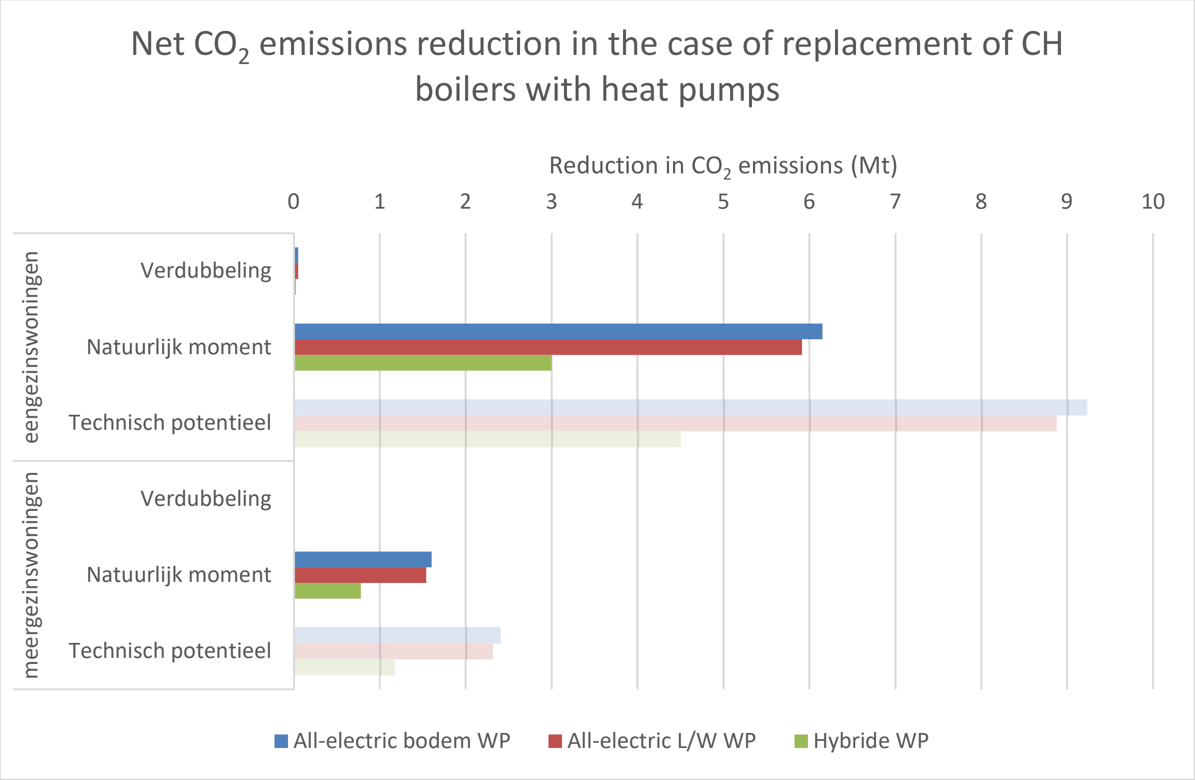


Figure D 2 Net CO_2 emissions reduction in 2030 as a consequence of the replacement of CH boilers with heat pumps for the different market developments.

The same calculations have been performed for the innovative technology, whereby it is assumed that, due to technical developments in heat pumps in the years to come, the system efficiency will have increased to 7.5 per cent by 2030, as indicated by the interviews. Here, we assume the same numbers of homes per market development. An improvement in system efficiency leads to a lower increase in electricity consumption and thus lower indirect CO_2 emissions from the electricity sector. In total, this prevents a net 1 per cent more CO_2 emissions when compared to current technology.

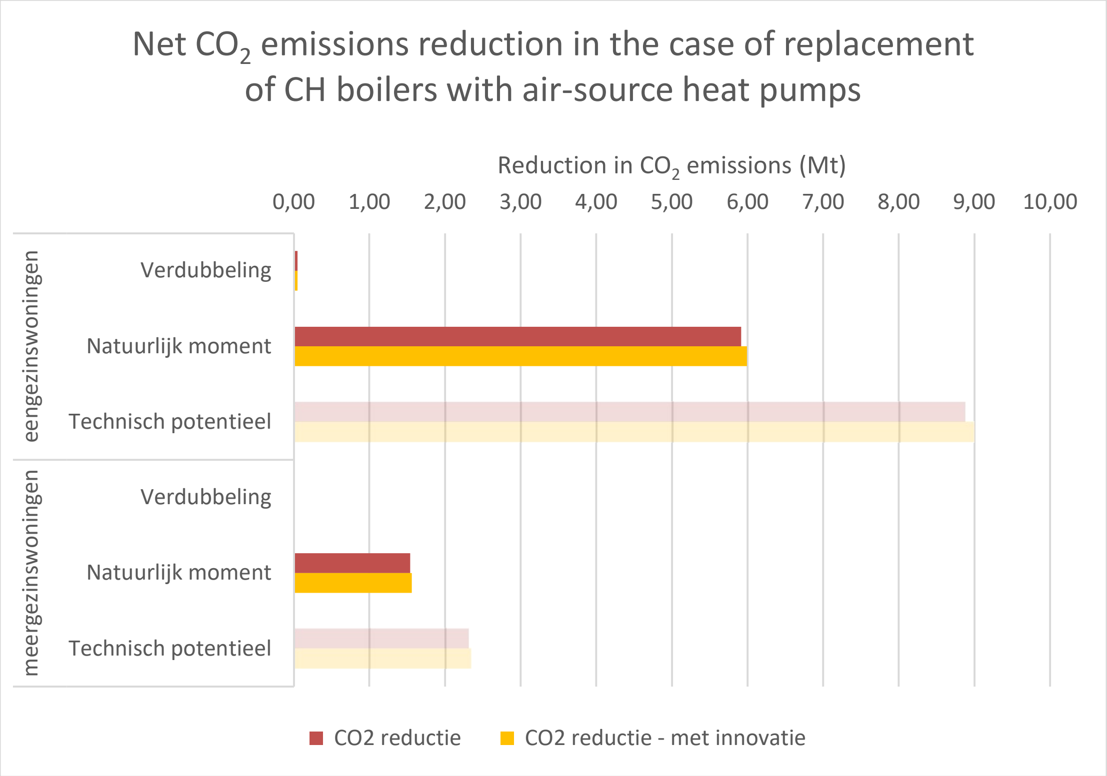


Figure D 3 A comparison of net CO_2 emissions reduction by 2030 from air-source heat pumps according to current technology and innovative technology.

Additional national costs

The additional national costs are the difference in annual costs for investment, maintenance and energy of heat pumps when compared to the CH boiler *and*, in addition, when compared to the Baseline. No insulation costs have been taken into consideration in this analysis. It has thus been assumed that the homes are suitable for low-temperature heating at the point in time at which they opt to install a heat pump. The point of departure is that these homes will be renovated autonomously to the level of insulation in accordance with the ‘Standard’ (RVO, 2022). This is a standard that indicates when a home is sufficiently insulated to be free of natural gas.

The annual investment costs of heat pumps are significantly higher than those of CH boilers (three to eight times higher than the CH boiler, on an annual basis, depending on the type of heat pump). The annual operating costs for heat pumps are a factor of two higher than for CH boilers, approximately. National energy costs (for the required energy carriers) when compared to CH boilers fall when heat pumps are used – a 30 per cent decrease in the case of ground-source heat pumps, a 10 per cent decrease in the case of air-source heat pumps and a 5 per cent decrease in the case of hybrid heat pumps. Calculated on the basis of the energy prices in the KEV 2021, the annual energy costs for hybrid, air-water and ground-source heat pumps are 84 per cent, 73 per cent and 55 per cent respectively of the annual costs of natural gas-fired CH boilers (reference). In the meantime, wholesale prices for both natural gas and electricity have risen sharply, thereby increasing the benefits from natural gas savings when compared to the additional electricity costs. The investment costs for ground-source heat pumps are higher than for air-source heat pumps due to the addition of ground systems, which means that the additional costs when compared to CH boilers are higher (Figure D 5).

Hybrid heat pumps require a lower investment, giving rise to lower additional costs than other types of heat pump. The difference in operating and energy costs when compared to a CH boiler is lower when compared to other types of heat pump.

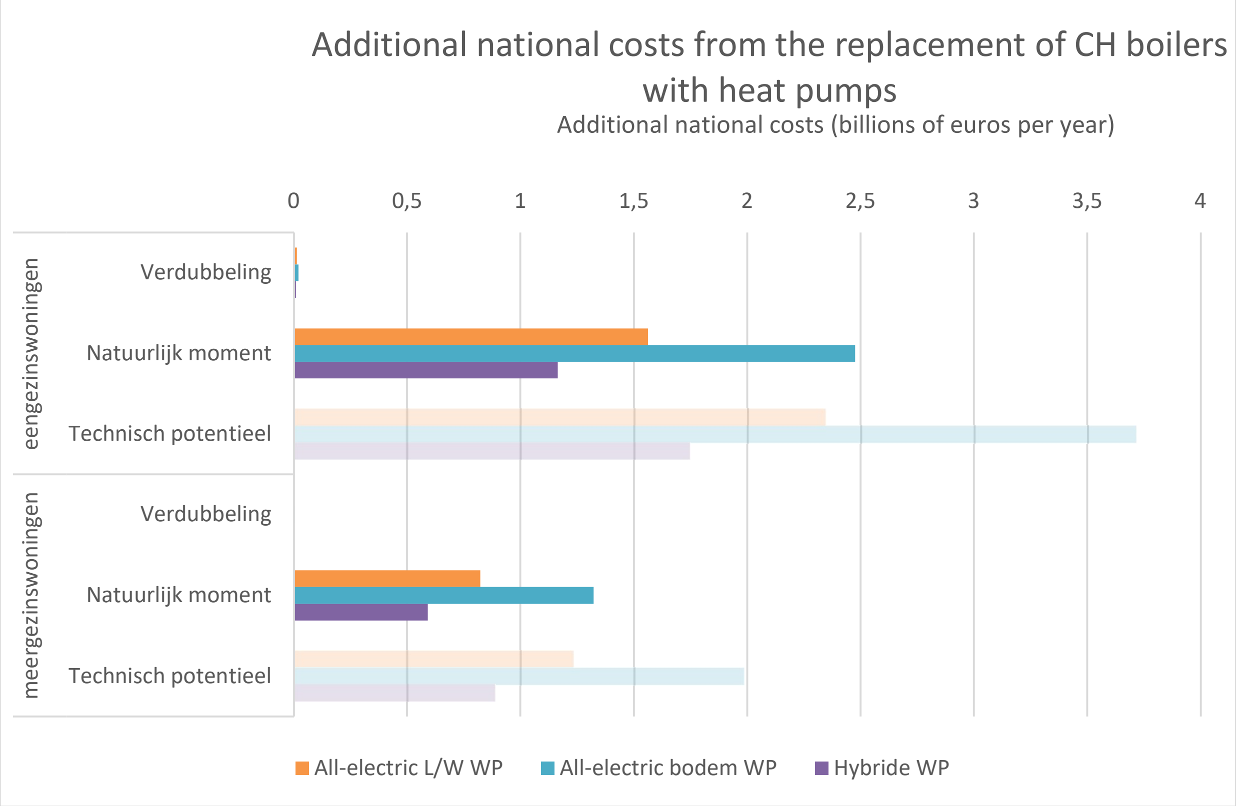


Figure D 4 Additional national costs in 2030 for replacement of CH boilers with different types of heat pump.

For the innovative technology, it is assumed that investment costs will have fallen by 15 per cent by 2030 on account of cost savings during installation, transport, storage and import, as indicated in the interviews. Depending on the type of heat pump, the fall in investment costs would lead to savings of between 15 and 20 per cent on the additional national costs on account of the lower investment, lower maintenance costs and savings on energy costs. See Figure D 5 for the results for air-source heat pumps (for ground-source heat pumps, see the annex).

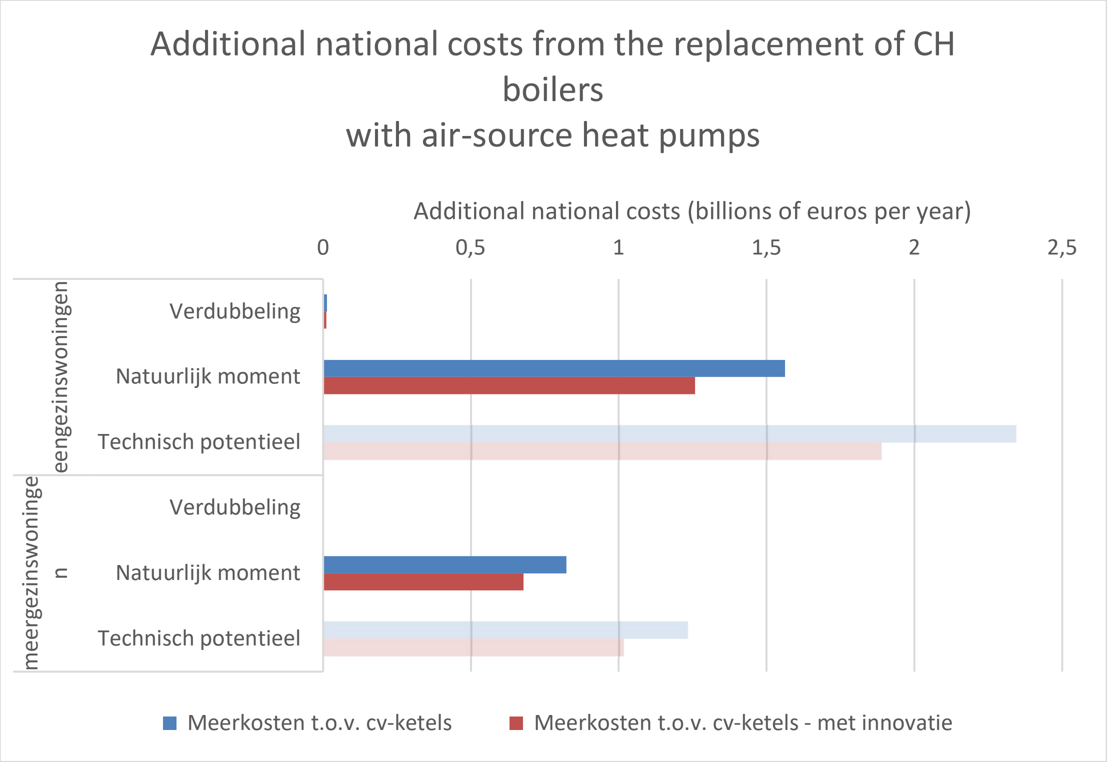


Figure D 5 Additional national costs in 2030 for replacement of CH boilers with air-source heat pumps according to the current technology and innovative technology.

Summary

The calculations show that replacing CH boilers with heat pumps can have a major impact on reducing CO_2 emissions from the built environment. The high initial investment costs may, however, act as a barrier. The interviews with experts indicate that they see limited scope for technological improvements in system efficiency (5 to 10 per cent) but see scope for improvement through more user-friendly and better-installed systems or for cost reduction (15 per cent), especially during installation, transport, storage and import. The exceptionally high energy prices at the time of compiling this report make the business case for heat pumps more favourable. Other important factors are trust in and familiarity with the heat pump, for both the homeowner and the installer. Further accelerating and simplifying installation appears to be a critical boundary condition for upscaling. Development of a plug-and-play installation method can contribute significantly to this goal by reducing the costs and labour hours required.

E. Sub-report – output systems

Introduction

Context

Output systems are an integral part of the system for heating (and cooling) in homes. The role of output systems is to transfer heat, which is currently generated by CH boilers and which, in the coming years, will be increasingly produced by devices such as heat pumps and LT district heating grids, to a room. Virtually all heating systems in homes in the Netherlands use water as a heat transfer medium, which is circulated between the heat source and the output system, often in the form of radiators.

In the current situation, therefore, most heating systems still use CH boilers operating at high temperature for the circulated water (60 to 90°C). One of the most important and striking trends in the heat transition is facilitating the use of lower system temperatures (30 to 55°C) to make the heat system overall more efficient. In the case of lower system temperatures, heat pumps can, for example, provide more heat per unit of electricity consumption, while district heating grids have lower heat losses. In this regard, innovative or advanced output systems play an important role and act as an 'enabler' for lower system temperatures.

TKI UE has the following points for attention when it comes to output systems, with a certain emphasis on low-temperature output systems, such as convectors and floor, wall and ceiling heating. Nevertheless, panel radiators with fans can also offer solutions.

- Reducing purchasing and installation costs
- Increasing efficiency and optimising output systems
- Adding and optimising the cooling capacity of output systems
- Improving output system integration into (renovation concepts for) existing buildings
- Reducing noise production
- Making output systems smarter
- Continuing development of circular concepts for output systems

Scope

The sub-report for output systems can be viewed as an addition to the sub-reports for heat pumps and district heating grids, which outline innovations relating to space heating from the perspective of heat generation. This sub-report looks at the output perspective and at specific innovations in relation to it.

Reading guide

The qualitative section of this sub-report comprises the 'Developments in the technology' and 'Boundary conditions for upscaling' sections and is based on desk research and interviews with Jan Verdonk (JAGA climate designers) and Andries van Wijhe (TNO). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the 'Potential market developments' and 'Impact' sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (2021) (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Combined summary of interviews with Jan Verdonk (JAGA climate designers) and Andries van Wijhe (TNO), including information from the literature

Heat transfer with the output system can, in principle, occur via two different mechanisms – radiation and convection (heat transfer by radiation and thermal displacement of heated air). In the case of (modern) panel radiators, both mechanisms are active. In the case of convectors, a large number of closely spaced fins promote the convection mechanism, thus making it the dominant mechanism. Floor and wall (or ceiling) systems are output systems whereby pipes are installed in floors, walls and ceilings and where heat transfer occurs via both mechanisms. In principle, all of these output systems are suitable for space heating, potentially with convectors having the edge and the benefit of that form of heat transfer (and thus controllability) being quicker than in the other output systems.

There are several developments, including optimisation of geometric configurations and research into materials, aimed at accelerating the heat transfer of output systems and making it more effective. In addition, there is also a trend involving the addition of fans at the bottom/top of a radiator or convector, to accelerate the convection process further and make it more efficient. The benefit derived from the fans depends heavily on the radiator/convector temperature, as at high temperatures (from around 50 to 60°C), the convection process is so effective that the fans are of less use. The lower the temperature, the more beneficial the effect of the fans. At lower temperatures, energy savings can be achieved at system level (particularly when heat pumps are used for heat generation). In view of the fact that convectors are designed based on the principle of the convection mechanism, fans achieve their greatest effectiveness with convectors.

Effective convection is also beneficial if the output system is to be used for summer cooling in addition to winter heating. Combined with reversible heat pumps, condensing cooling can be achieved, where water is circulated at a temperature of around 10°C (actively cooled by the heat pump). This requires a condensate drain to be integrated into the output system. Such systems are already available on the market. Moderate cooling (active or passive), where water is circulated at a lower temperature of around 20°C, is also a possibility. Generally speaking, panel radiators are less suitable for cooling because the flow pattern of cooling water in a panel radiator is unsuitable. Passive cooling via floor, wall and ceiling output systems is a possibility.

Reducing purchasing and installation costs

The investment costs comprise partly material costs and partly installation costs (and/or construction costs), whereas, in the case of floor, wall and ceiling heating, the installation costs are associated with major construction work and are thus dominant. When it comes to renovation, costs depend heavily on the system that is chosen. For some output systems, it is often possible to connect them directly to the existing piping system, while others will require construction work. This can increase the cost price. It is expected that, due to increasing numbers and innovations, a cost price reduction can occur.

Increasing efficiency and optimising output systems

One effect that is frequently assumed to be beneficial for energy performance is the use of night-time reduction (setting the thermostat lower at night). Whether this is actually beneficial, however, depends to a large extent on the specific circumstances (including the heat demand of the home and the type and capacity of the generation system). This is because reheating a home in the morning or after the home has been vacant for a while takes time. In the case of more rapid systems, such as panel radiators and/or convectors, this has a positive effect on energy performance, while (traditional) floor heating requires a continuous floor temperature. Heating a (traditional) floor heating system with night-time reduction typically consumes more energy. This is because the floor has to be heated to a certain temperature before it will begin to emit additional heat. This can be remedied by installing a dry-construction system.

Controlling different areas of a home separately can be of particular interest when it comes to optimal use of output systems (this concept is known as ‘zone control’ or ‘compartmentalisation’). Whether or not the concept can actually help to save energy depends on the specific situation. Zone control, particularly when a heat pump is used, can give rise to efficiency losses due to the increased frequency of the heat pump switching on and off. Integration of a hot water tank into the heating system can offer a solution to this problem, but there will still be system losses that are typical for hot water tanks. There are currently systems that are capable of keeping these losses to a minimum, where the buffer is extremely small. Optimisation with zoning control is thus a complex system matter and cannot always be used generically.

System configurations, in which output systems are combined with/connected to ventilation systems (including heat recovery units) are also under development. These systems aim for integrated, energy-efficient solutions for optimising the indoor climate of homes.

Another trend connected to energy performance is the use of dirt separators in the water cycle (in the case of a CH boiler or heat pump). A dirt separator removes the dirt (including magnetite) that accumulates in the circulated water over time and that, in addition to other problems, can cause the output capacity of output systems to be reduced. Without dirt separators, a reduction of around 10 per cent may occur over a ten-year period.

Improving output system integration into (renovation concepts for) existing buildings

As an integrated part of the heating (and cooling) system, the installation of innovative (low-temperature) output systems is associated with the installation of low-temperature heating systems (heat pumps, LT district heating grids). Panel radiators and convectors (with and without fans) can be quickly connected to often already existing pipe systems in the home and thus installed at natural points in time, such as replacement during conversion or renovation.

A development known as the dry-construction system is available for floor-heating systems. With this, the floor-heating system can be installed on existing floors with the aid of plates fitted with pre-formed profiles (for the heating pipes) and then finished on top with a screed. This development makes it easier and quicker to install floor heating during renovation and allows for systems to be installed on wooden storey floors on account of its relatively low weight. Potential market access is thus expected to be greater than for more traditional systems (which are cast in concrete). An additional benefit of dry-construction systems is a higher heat-up rate, as heating is not retarded by the large thermal mass of the surrounding concrete.

Reducing noise production

Noise from output systems, produced by flowing water and/or fans, can be perceived as irritating and is thus the focus of further development. It is expected that a new standard will be introduced relating to the noise level of output systems.

Making output systems smarter

Except in the case of very significant functionality failures in an output system, users are generally unaware of how well a system is performing. Some developers are currently working on monitoring systems designed to supply information about parameters, such as the efficiency of output and to make maintenance needs visible/accessible and electronically invokable (e.g. via an app).
In addition, smart radiator buttons are also gaining in popularity, enabling active control of room temperatures via smartphones. In the case of integrated heating and ventilation systems, this also includes control of humidity and CO_2 levels in the air.

Air quality

Panel heaters can be responsible for dust and other pollutants in the air. This is the case at higher output temperatures in particular, as the high surface temperature gives rise to more convection currents than would be the case with a lower temperature. The trend towards lower-temperature heating systems is thus giving rise to improved air quality by default. If fans are used, the challenge relating to air quality is greater. Filter systems are, however, available to capture dust, and these can be fitted to the bottoms of panel radiators or convectors. Radiator cleaning with a vacuum cleaner (once every two years) is also an option.

Boundary conditions for upscaling

We have referred to a number of different developments relating to output systems, including the optimisation of geometric configurations and materials, reduced noise production and condensate drainage for cooling, but these developments do not in any way impede the introduction of low-temperature heating. A crucial boundary condition for upscaling of advanced output systems is thus growth in the low-temperature heating systems market. In view of the high labour intensity required for the installation of output systems, particularly for floor-heating systems, a further boundary condition is the availability of sufficient labour capacity in the installation industry to undertake the work in question.

Potential market developments

Description

Considering the trend towards low-temperature heating systems, this sub-report assumes similar assumptions as those made for district heating grids (which are in a similar order of magnitude as for heat pumps) when it comes to market share. On this basis, the market share is the number of existing homes connected to a district heating grid between 2020 and 2030. We assume that an LT output system will need to be added to these homes.

Baseline

The assumption applied for the increase in the market share of homes with LT output systems is around 36,000 multi-family homes and 48,000 single-family homes for the Baseline scenario up to 2030, giving a total of 84,000 homes.

Doubling

The doubling when compared to the Baseline is equivalent to an increase of a further 84,000 homes (36,000 multi-family homes and 48,000 single-family homes).

Technical potential

For the assumption relating to the technical potential, we assume that 100 per cent of existing homes located within an area classed as having a building density of high or medium will be connected to the district heating grid by 2030. That means over 6,000,000 homes (2.5 million multi-family homes and 3.5 million single-family homes). As stated above, this is in no way intended as a prediction, but to give an indication of the theoretical range.

Table E 1 Description of the potential market developments of output systems, the impact of which has been calculated in this sub-report

Potential market developments for output systems	
	Description
Doubling	84,000 homes with LT output systems
Technical potential	6 million homes with LT output systems
	Boundary conditions
Doubling/technical potential	- Growth of LT heating systems (heat pumps and (V)LT district heating grids - Availability of sufficient labour capacity

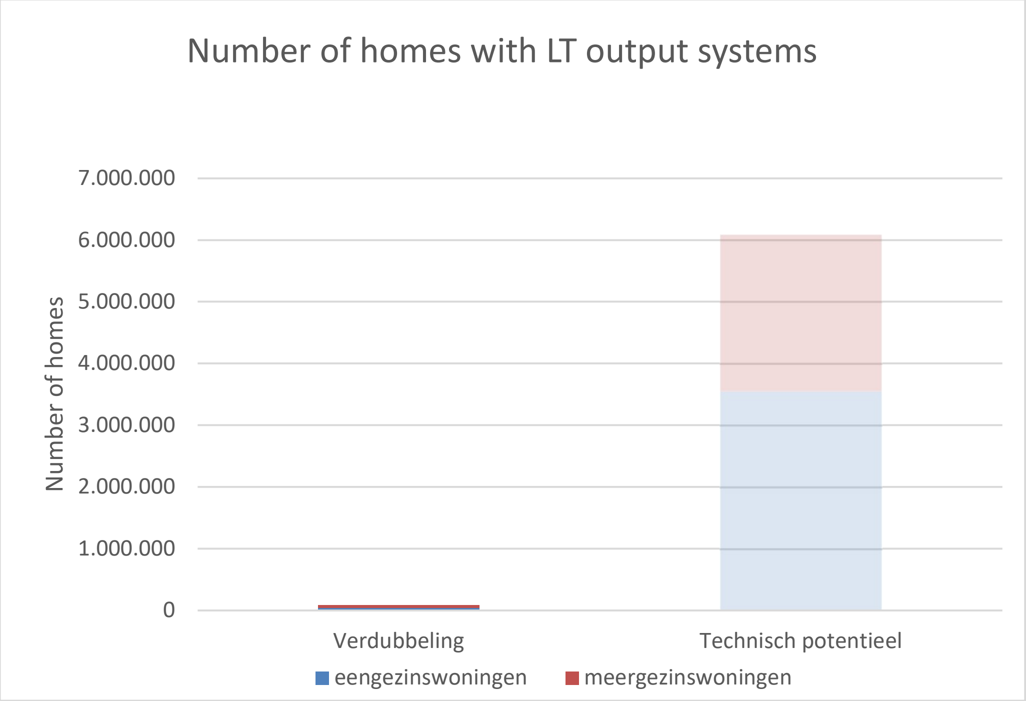


Figure E 1 Number of homes when compared to the Baseline in which LT output systems are added to heating systems of LT district heating grids in 2030.

Requisite innovations

When it comes to output systems, there are a number of different innovations, which focus primarily on use in low-temperature heating systems. Developments are available to improve the efficacy and speed of heat output or for better use in renovation concepts. Another important development is that innovative output systems are being given dual functionality – namely, heating in winter and cooling in summer. In addition, accelerating the installation time with plug-and-play solutions is important, such as through the integration of pipes/convectors into prefabricated façades or systems that can be easily connected to existing pipe systems.

Choosing between specific solutions, such as radiators, convectors and floor, wall (and, if applicable, ceiling) heating is a complex consideration for users, in which costs as well as aesthetics and individual convenience expectations and perceptions play a role. As enablers of low-temperature heating systems, advanced output systems are important to accomplishing LT heat systems.

Impact

This section calculates the potential impact of a sub-topic for different market developments. It focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. This means that other impacts of higher market share or of an innovation are not taken into consideration.

As stated in the introduction above, output systems are an integral part of the heating system and can be seen as enablers for lower system temperatures. CO_2 emissions reduction is thus related to the low-temperature heating system and not to the output system. In this quantitative section, we therefore look solely at costs, where two types of output system are included – (fan) convectors and floor heating. It has been assumed that the output system in the home must be fully replaced during renovation, based on Arcadis 2020 cost indices for each home (Arcadis, 2020). If only a portion of these costs is incurred (perhaps because older radiators like those in bedrooms are not replaced), they will fall in proportion.

National costs

National costs have been calculated for two types of output system – floor heating and high-efficiency convectors. The decision to opt for these systems is based on a focus on very low water temperatures of around 30°C, for which these output systems are suitable (which is different to fans, which are retrofitted to existing radiators[9]). The results for the addition of both types of output system when accomplishing LT heating systems are shown in Figure E 2. In the case of floor heating, costs are higher due to the (significantly) higher investment costs (Arcadis, 2020). In the ‘doubling’ scenario, the national costs amount to several tens of millions of euros and are thus limited (in view of the small number of homes in this scenario). In view of the larger number of homes, the national costs for the technical potential amount to significantly more – in the order of hundreds of millions to several billions of euros.

From the higher costs associated with floor heating, it is not necessarily possible to conclude that this output system will be installed less frequently, as other aspects, such as aesthetics and comfort, play an important role in the decisions of users, alongside costs.

---

[9] Retrofit fans are characterised by much lower costs and could form a favourable solution in heating systems operated at higher water temperatures (such as 50°C).

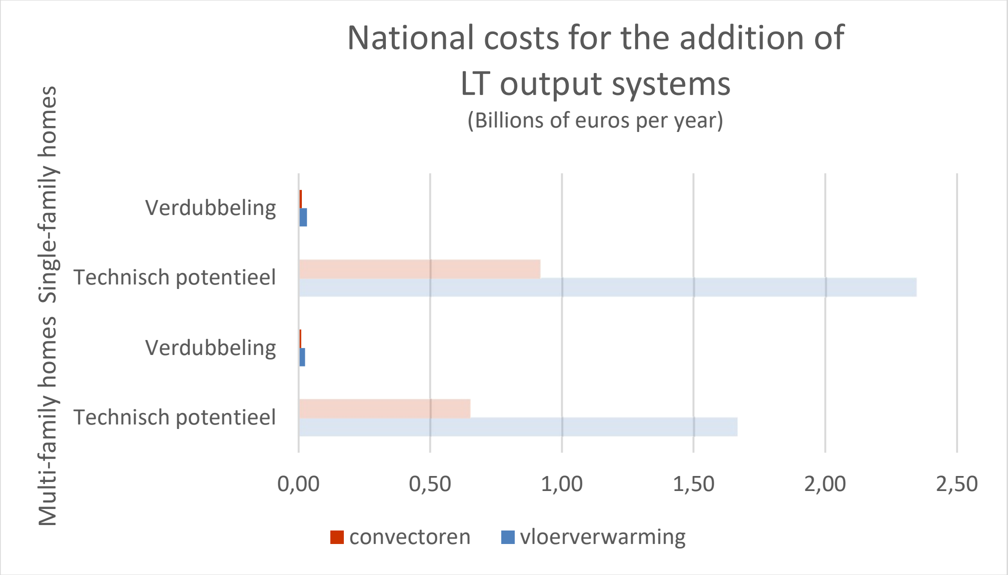


Figure E 2 National costs when compared to the Baseline in which LT output systems are added to heating systems of LT district heating grids in 2030

Summary

LT output systems are an important and integral component of LT heating systems. There are a number of different developments, all of which focus on improving the efficacy and speed of heat output (such as with fans) and on better use in renovation concepts. There is a trend towards dual functionality, primarily heating in winter and cooling in summer. Output systems that are currently available, such as floor heating and advanced convectors, are already suitable for use in heating systems operating at very low water temperatures of around 30°C. Floor-heating systems are characterised, however, by high investments costs, and the prospects for a reduction in costs are limited (in view of the relatively high labour intensity of installation). For heating systems operating at higher water temperatures (such as 50°C), retrofitting fans may be a favourable solution, giving rise to much lower costs. The further development of concepts such as night-time reduction and zone control is a complex system issue, for which the potential benefits depend on different heating system parameters.

F. Sub-report – domestic hot water systems

Introduction

Context

Domestic hot water is expected to play an increasingly important role in energy demand in the built environment. The distribution of heat demand between space heating and domestic hot water is now 80 per cent to the former and 20 per cent to the latter (Segers, Niessink, van den Oever, & Menkveld, 2020). There will be a certain shift towards domestic hot water (Moerman, Blokker, van der Blom, & van Veelen, 2016) as heat demand for space heating decreases on account of the increasing roll-out of insulation measures and less severe winters. At the same time, demand for domestic hot water, primarily for showers, is likely to remain more or less constant (Van Petersen, 2021). Domestic hot water will, in the longer term, represent a significantly higher share of the overall heat demand in homes and could, in some cases, become the dominant factor. The importance of domestic hot water is also high, as the trend towards low-temperature heating (<55°C) means that domestic hot water cannot be connected without additional facilities being put in place. The latter is related to the requirements relating to potable water quality and safety as stipulated in NEN 1006, which include a minimum temperature for domestic hot water from tapping points (for functional requirements) of between 55 and 60°C.

TKI UE has formulated a number of points for attention for this sub-programme (2.2 of MMIP4):

- Increasing the energy efficiency of domestic hot water systems within the applicable legionella requirements
- Improving the integration of domestic hot water systems into (renovation concepts for) existing buildings
- Making domestic hot water systems smarter and offering flexibility
- Accelerating and upscaling the installation process and circularity

Scope

As heat demand in homes includes both space heating and domestic hot water, the latter is also covered by the sub-reports on heat pumps and district heating grids. The sub-report for domestic hot water is a supplement to this and looks more closely at specific innovations in that field – innovations that were not described in the other sub-reports referred to. The focus of the MMIP is on technologies for shower water savings, shower water recycling, heat recovery, legionella prevention and usability in homes, among other things. There is also an interface with technologies for the generation of sustainable heat for shower water, such as by (booster) heat pumps, solar thermal, etc. As mentioned above, these technologies are covered by other sub-programmes[10] of MMIP4, and the innovations relating to them are therefore not described in this sub-report.

Reading guide

---

[10] The generation of sustainable heat for domestic hot water is covered by the following sub-programmes of MMIP4:

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ sections and is based on desk research and the interviews with Frank Oesterholt (KWR) and Piet Jacobs (TNO). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (2021) (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Increasing the energy efficiency of domestic hot water systems within the applicable legionella requirements

An important general aspect for the energy performance of domestic hot water systems is the temperature at the tapping point. A minimum temperature of ≥55 to 60°C is currently used for domestic hot water systems in the Netherlands, with the precise temperature dependent on the building type/function (Van Petersen, 2021). In view of the fact that the average shower temperature is considerably lower (around 40°C), however, there is, in principle, the option of reducing the water temperature at the tapping point to 40 to 50°C as a way of boosting energy performance. For gas boilers and biofuel boilers, the achievable energy saving from temperature reduction may be low, to a maximum of 2.5 per cent, but for an individual combi heat pump with an instant water heater, energy savings could be as high as 20 per cent (Van Wolferen).

In practice, reducing the temperature is only possible if safety requirements relating to legionella prevention can also be satisfied at the same time. Those requirements are the reason for the minimum temperature specified in NEN 1006 (general requirements for water supply installations). Based on research by Berenschot and KWR, a recent letter to parliament referred to the possibility of the standard being tightened further, including a rule that, in home systems, the hot water temperature in the hot water unit must be a minimum of 60ºC throughout. The consequences of these recommendations for national energy consumption and usage options of natural gas-free systems are currently being investigated by KWR in a follow-up study by TKI UE.

Innovative methodologies for legionella prevention are under development, which means that a standard with lower temperatures could, in principle, be safe. These methods include those that use UV light, physical filtration or thermal pasteurisation, which are described in more detail in (Van Petersen, 2021). The potential use of these methods in practice depends, however, on the relevant amendments to NEN 1006. At present, it is impossible to predict whether lower-temperature drinking water systems will be legally permissible in the Netherlands by 2030.

Other developments designed to improve energy performance that are not dependent on a reduction in the hot water temperature are systems or components for hot water saving, hot water recycling and heat recovery. There are various technologies and configurations under development to this end, some of which are already in use, although, with the exception of hot water saving, only to a limited extent at present. When it comes to hot water saving, relatively simple water-saving shower heads have been available for many years, finding their way into around half of all households in the Netherlands (Van Petersen, 2021). In this particular area then, there is no major prospect of further innovation.

Systems for hot water recycling and heat recovery have also been available for some time and are currently undergoing further development. In the case of water recycling (recycle shower), the hot shower water is reused immediately after being cleaned by filtration and UV radiation. The savings that can be achieved on both energy and water requirements in this kind of system are high, at around 80 per cent. In the case of heat recovery, heat exchangers are used to recover heat from the used shower water to then preheat the cold-water connection to the shower and/or hot water heater. Energy performance depends on the specific configuration and heat losses. With the best configurations, such as those based on innovative helix heat exchangers, up to 60 to 70 per cent of the heat coming from the shower head (and 80 per cent of the heat entering the heat exchanger respectively) can be recovered at system level. There are simpler and/or retrofit configurations with lower system efficiencies, starting at 20 per cent (Jacobs, Vijlbrief, & Kemp, 2020).

At system level, there are additional options for improving the energy performance of domestic hot water systems, such as by limiting heat losses in water pipes and boiler cylinders – in the latter, there is a potential trend towards vacuum-insulated cylinders (see the ‘Small-scale heat storage’ sub-report).

Taking all of the aforementioned developments into consideration, it can be stated that, when compared to the domestic hot water system that is currently dominant in the Netherlands (the high-efficiency combi boiler), significant improvements in energy performance can be achieved with heat recovery or hot water recycling by themselves. Energy savings of a minimum of 20 per cent can already be accomplished, even with relatively simple (retrofit) heat-recovery systems. Energy saving figures of 60 to 80 per cent are feasible with the most advanced systems, thanks to water recycling or efficient heat recovery. These savings are in addition to savings on the domestic hot water heating side, such as with heat pumps or district heating grids (see the sub-reports on heat pumps and district heating grids).

Making domestic hot water systems smarter and offering flexibility

The large variation in energy performance, which depends on configuration and/or decline in functionality (such as due to heat exchanger soiling), implies that there is a need to develop monitoring systems that show how well a particular configuration performs in practice. With current systems, there are barely any ways for users to discover whether the promised/expected energy performance is actually accomplished. Monitoring systems are currently under development (electronically invokable, such as via an app) that show how well a particular configuration performs in practice.

Improving the integration of domestic hot water systems into (renovation concepts for) existing buildings

Increasing the sustainability of domestic hot water systems may be associated with a major renovation, which may involve spatial constraints (such as for larger boiler cylinders or the installation of heat exchangers that are more than two metres long) and installation time/costs (such as for the installation of water pipes between the heat exchanger and the hot water heater and shower mixer tap). In the renovation of multi-family homes, it is not possible to use conventional shower heat recovery (under the floor level of the bathroom). As such, the majority of innovative systems thus far have been installed in new buildings, and fewer have been installed in existing homes. The development of compact systems – and concepts – which require less of a major conversion is a development direction that lowers these barriers.

The integration/matching of components, such as heat recovery units, boiler cylinders, water pipes with heat generators and optimisation at system level can not only contribute to greater compactness of domestic hot water systems but can also improve the efficiency of the overall system. One example is an innovative shower system in which the hot water heater is integrated into the shower itself, thereby removing the need for adjustments to supply pipes during renovation. Implementation of this system, in which hot water heating is carried out by a heat pump being fed by a VLT district heating grid (15°C), is still under development. In addition, the design of this system also provides for space heating (although only for very well-insulated homes), thus offering a solution for the overall heat demand of homes.

Reducing purchasing and installation costs and operation

Investment costs for more straightforward heat recovery systems are around EUR 500 to EUR 1000, with limited prospects for further reduction. In the case of more complex systems, such as the recycling shower or integrated heat pump/heat recovery shower, investment costs are higher, coming in at around EUR 4000 to EUR 6000. These more complex systems are often designed as prefabricated solutions, thus creating a more standardised product and giving rise to shorter installation times (and costs).

Boundary conditions for upscaling

A boundary condition for upscaling of (more) sustainable domestic hot water systems is that both users and installers pay greater attention to the technological possibilities of heat recovery. Based on the information collated for this report, knowledge of heat recovery remains limited amongst both users and installers. Technologies such as heat recovery should be available in the installation industry's portfolio as standard, which is not currently the case. This could lead to more of these technologies being implemented, at least in the case of more extensive renovation. In addition, a decrease in the cost of more expensive, but also most effective systems, could help to promote upscaling. This also requires shorter installation times and, where possible, standardisation.

To come to a definitive conclusion as to whether temperatures lower than the current 55 to 60°C can be used safely, clear insights are needed into the efficacy and failure risks of legionella management techniques, other than thermal. For improved user friendliness, monitoring systems ought to be developed to help make it clear to the user whether the systems, such as heat recovery systems, are performing as desired.

Potential market developments

Description

This sub-report makes similar assumptions to those made for (V)LT district heating grids when it comes to market share, as homes with low-temperature heating need a separate supply for domestic hot water. In the sub-report in question, the market share comprises the number of existing homes connected to a district heating grid between 2020 and 2030. This point of departure for the estimate of market share does not mean that the domestic water systems in question will be used exclusively in homes that are connected to (V)LT district heating grids.

Baseline

The assumption used for the increase of the market share of homes with separate domestic hot water systems is around 36,000 multi-family homes and 48,000 single-family homes for the Baseline scenario up to 2030, giving a total of 84,000 homes.

Doubling

The doubling when compared to the Baseline is consistent with an increase of a further 84,000 homes with a separate domestic hot water system (36,000 multi-family homes and 48,000 single-family homes).

Technical potential

For the assumption relating to the technical potential, we assume that 100 per cent of existing homes located within an area classed as having a building density of high or medium will be connected to the district heating grid by 2030. That means over 6,000,000 homes (2.5 million multi-family homes and 3.5 million single-family homes). As stated above, this is in no way intended as a prediction but to give an indication of the theoretical range.

Table F 2 Description of the potential market developments for domestic hot water systems, the impact of which has been calculated in this sub-report

Potential market developments for domestic hot water systems	
	Description
Doubling	Doubling when compared to the Baseline of the number of existing homes connected to a low-temperature district heating grid by 2030
Technical potential	All existing homes in an area with a heat density class of high or medium connected to a low-temperature district heating grid by 2030
	Boundary conditions
Doubling/technical potential	- More familiarity with the technology behind domestic hot water systems amongst users and installers - Reduced installation times and lower costs

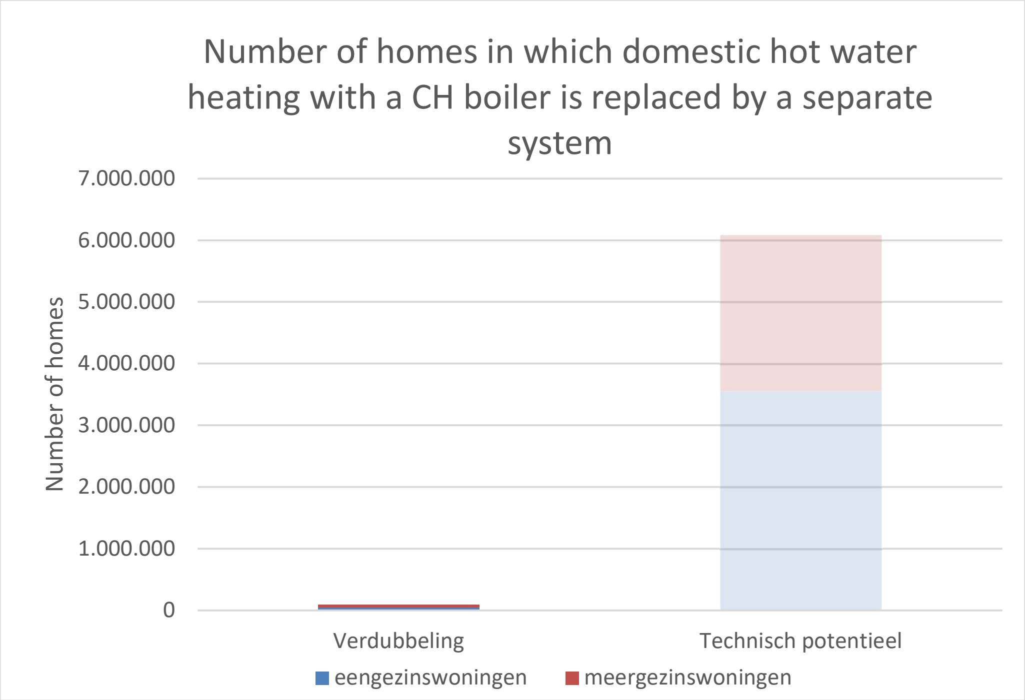


Figure F 1 Number of homes when compared to the Baseline in which domestic hot water heating with a CH boiler is replaced by a separate system by 2030.

Requisite innovations

In an ideal world, a breakthrough will be achieved for legionella-safe domestic hot water heating, allowing the temperature at the tapping point to be reduced below the current 55 to 60°C. In that case, many low-temperature heating systems will be able to supply domestic hot water directly, without any need for an upscaling of separate domestic hot water systems. In addition, particular innovations are needed to help eliminate existing barriers to upscaling, i.e. relatively high costs, installation processes viewed as far-reaching, spatial limitations (particularly in smaller homes). Accomplishing maximally efficient systems also requires a continuation of innovations for system optimisation, giving rise, for example, to the minimisation of downtime losses and the maximisation of heat generation efficiency.

Impact

This section calculates the potential impact of a sub-topic for different market developments. It focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. This means that other impacts of higher market share or of an innovation are not taken into consideration.

The following details the impacts for two specific technologies. One technology is an instant water heater, which serves as a reference point (such units are sometimes used in the separate domestic hot water systems that are currently available). The other (innovative and still under development) technology is a system in which domestic hot water heating with a (water-water) heat pump and heat recovery are integrated into a single system. The decision to opt for this example is based on the fact that many of the innovations outlined in this sub-report have been accomplished in this system, such as high-efficiency heat recovery. The system-integrated heat pump is expected to give rise to a very high heat-generation efficiency (SPF 8). The assumptions and key figures are explained in further detail in the annex.

CO_2 emissions

Replacing a CH boiler with an instant water heater or the innovative system (heat pump + heat recovery) for domestic hot water heating helps to reduce CO_2 by avoiding direct CO_2 emissions from the CH boiler. This emissions reduction is, however, reduced by the (much smaller) indirect emissions as a result of the electricity consumption by the replacement system. Emissions reduction for the heat-pump system is higher because its electricity consumption is significantly lower (on account of its high SPF of 8). Still, the total emissions reduction in the ‘doubling’ scenario for both systems is limited in absolute terms (<0.1 Mt CO_2). This is because of the assumed limited market growth to 2030. Considering the much higher number of homes, emissions reduction for the technical potential is obviously much higher, at around 1.6 Mt for the instant water heater and 2.2 Mt for the heat pump with heat recovery.

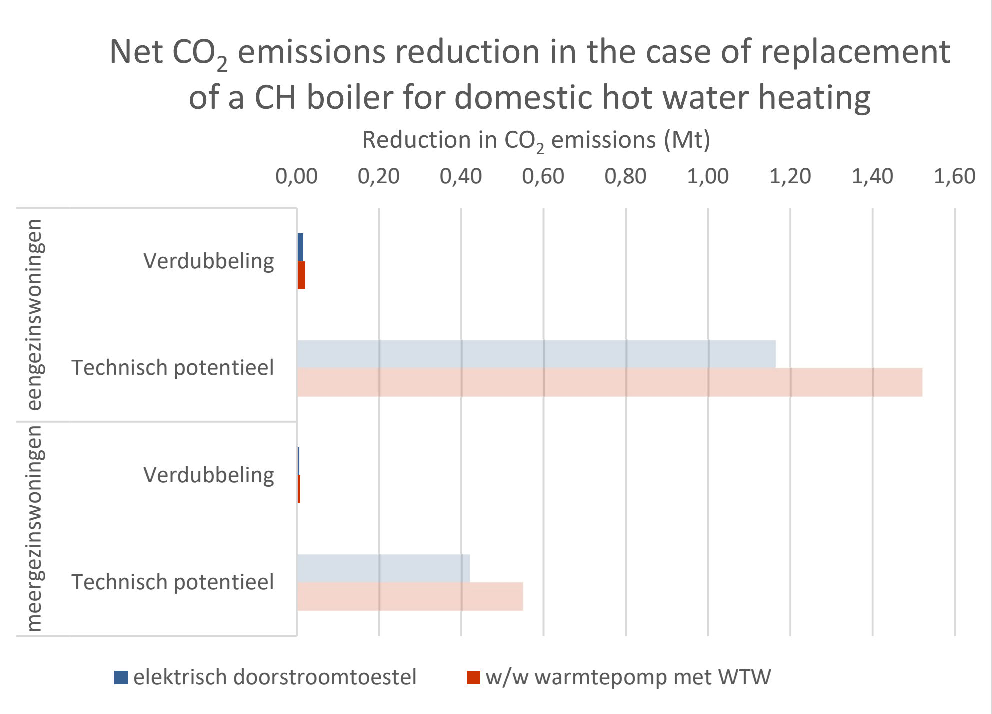


Figure F 2 Net CO_2 emissions reduction in 2030 as a result of domestic hot water heating with an instant water heater or water-water heat pump with heat recovery instead of a CH boiler

Additional national costs

Replacement of a CH boiler with an instant water heater or the innovative system (heat pump + heat recovery) for hot water heating renders some of the costs for a CH boiler unnecessary. Here, we assume that 20 per cent of the total costs of the CH boiler will be unnecessary (investment costs and operating costs). This assumption is based on the distribution of heat demand that will be typical in 2030 (20 per cent for domestic hot water and 80 per cent for space heating). For heat pump + heat recovery, this ignores the fact that the system can also be used for space heating at the same time (if this had been taken into consideration, the costs would be much lower). The superfluous costs of the CH boiler do not outweigh the costs of the replacement systems (instant water heater or water-water heat pump with heat recovery). The costs of the water-water heat pump with heat recovery are higher than those for the instant water heater. This is because the investment costs are higher and in spite of the reduced electricity consumption. Considering the modest assumed market growth to 2030, additional national costs for the ‘doubling’ scenario are limited in an absolute sense.

For the technical potential, however, the additional national costs are higher due to the higher number of homes involved.

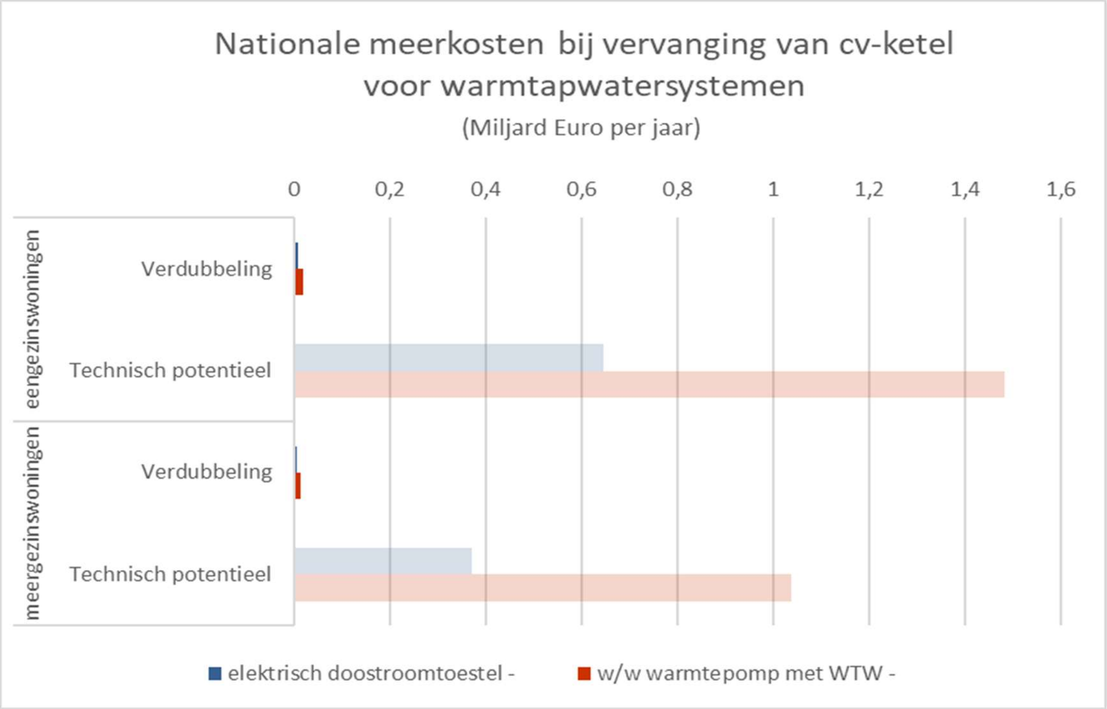


Figure F 3 Additional national costs in 2030 as a result of domestic hot water heating with an instant water heater or water-water heat pump with heat recovery instead of a CH boiler

Summary

A point for attention when it comes to domestic hot water is the expected future increase in the share of the heat demand for domestic hot water (as the heat demand for space heating decreases with better insulation and milder winters).
In addition, the trend towards low-temperature systems for space heating means that, for domestic hot water systems, a separate system must be provided in many cases. When it comes to domestic hot water systems, there are promising innovations that could help to improve energy performance for domestic hot water heating substantially and make it more sustainable. As an example, even with relatively straightforward retrofit systems for heat recovery, an energy saving of at least 20 per cent is possible. With more advanced systems for shower-water recycling or shower-water heat recovery, this rises to 60 to 80 per cent. Various systems are under development, which could help to make domestic hot water systems virtually emission free, such as through the integration of heat pumps for domestic hot water heating and heat recovery for energy savings. To accomplish upscaling of these types of system, greater familiarity amongst users and installers is needed, in addition to falling costs and low-threshold installation processes, as well as the introduction of pilot projects.

G. Sub-report – ventilation systems

Introduction

Context

A large proportion of homes rely on seams and gaps for their ventilation. Applying draught proofing to a home during renovation, in addition to insulation, reduces the natural supply of fresh air and the removal of contaminated air. This has an impact on the air quality and can thus have an impact on health, even if that impact is not always immediately perceptible. Since September 2021, the WHO has recommended an average of a maximum of five microgrammes per cubic metre of fine particulate, measured over a year. This is a tightening by a factor of two when compared to the earlier requirement. This means that, in almost 98 per cent of homes, the annual average value recommended by the WHO for PM2.5 is exceeded (Jacobs, 2021). In addition to removing air pollutants, a ventilation system with filters can also clean the air, helping to capture virus particles from indoors and stopping them from being recirculated, and preventing pollen and fine particulate from outdoors from entering.

In MMIP4, TKI UE outlines the following points for attention for ventilation systems:

- Reducing purchasing and installation costs
- Increasing (system) efficiency and optimising ventilation systems
- Reducing noise production
- Simplifying the maintenance process and making it smarter
- Further developing ventilation systems and making them smarter
- Integrating improvements in ventilation into overall renovation concepts

Scope

The focus of this sub-report is on accomplishing adequate ventilation in existing homes in the most energy-efficient way possible.

Reading guide

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ sections and is based on desk research and the interviews with Wouter Borsboom (TNO) and Sjoerd Kleijn Velderman (Endule). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (2021) (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Problems in existing buildings

After draught proofing in the home to help suppress heat loss, it is important that there is adequate ventilation to support air exchange. At the same time, the aim is to save as much energy as possible. It is also important that ventilation systems are as economically efficient as possible. In terms of air quality, the 2012 Dutch Buildings Decree states the following:

Section 3.35 Conversion
1. Sections 3.29 to 3.34 apply accordingly to the partial renovation or alteration or extension of a structure, whereby the level obtained by law is used as the basis instead of the level specified in those sections.

NEN 8087:2001 defines the ‘level obtained by law’ as:
‘The air exchange achieved through leaks in the building envelope, such as gaps and seams (infiltration), is also considered air exchange in the sense referred to above.’

This means that the level of (natural) ventilation before renovation must be maintained after renovation. This requirement is not enforced, however.[11] In principle, it is also possible to comply with the ‘Standard’ (RVO, 2022) without having used a ventilation system. The reduction in air supply through draught proofing is thus not sufficiently compensated in all cases. Additionally, ventilation systems still do not always satisfy the preferences relating to energy consumption and comfort, perhaps because they are not installed properly. Furthermore, in practice, developers and homeowners do not explicitly steer towards adequate ventilation, in part due to a lack of knowledge and insight into how the system works and into how ventilation can benefit health and produce energy savings. Information on operation and the current indoor air quality and energy use of the building and ventilation system would give the user greater insight into the performance of the ventilation system. This lack of insight makes it tricky for users to hold contractors accountable for supply of a good and properly functioning ventilation system. The ‘Healthy homes’ programme of requirements has recently been developed and sets performance requirements for air, climate, light and noise (Binnenklimaat Nederland, 2022). This programme of requirements can be used for design at three quality levels.

Other points for attention relating to ventilation in existing buildings are:

1. Many homes (including homes built after 2000) still appear to have a problem with moisture and mould in the bathroom. Mechanical ventilation often seems to be inadequate when it comes to removing moisture, perhaps because it is on the high setting for an insufficient amount of time. Demand-based control could help, perhaps with a moisture sensor in the drain. In the event of installation of a decentralised mechanical ventilation unit, there is often a blockage of the natural discharge channel, thereby reducing ventilation.

2. Extractor hoods in kitchens are often insufficient at removing the concentration of fine particulate from cooking emissions. This is because the requirements have been formulated based on the removal of moisture during cooking. In practice, this extraction point is in some cases absent even after renovation.

---

[11] The requirements in the Buildings Decree (and soon the ‘Buildings in the Living Environment Decree’) are intended as a minimum safety net for the prevention of immediate and serious accidents and harm to health, such as collapse and fire. In many cases, the minimum requirements concerning ventilation in the Buildings Decree are applied as maximum performance, but this does not mean that indoor air cannot have negative impacts on health or, indeed, comfort.

3. Residents are unfamiliar with how the ventilation system works and needs to be maintained. In many cases, residents do not know how to maintain grilles, valves and ducts or how to change filters so that the unit can continue to operate as intended.
4. Many residents are also unclear on how mechanical ventilation should be operated, such as the position at which a ventilation system should be set and the effect of opening or closing ventilation grilles and windows. This can give rise to too little ventilation, and in some cases, to a ventilation system being set too high for too long.
5. Night-time ventilation to cool the home, by opening windows and doors, is best done over night and early in the morning. In view of the risk of a break-in, residents sometimes do not do this. According to the Buildings Decree, night-time ventilation needs to be intruder-proof when closed, but not when it is open, which is exactly what night-time ventilation ought to be. NTA8800 states that night-time ventilation must be intruder-proof, but in practice, such ventilation is either unavailable or cannot be tested.
6. If the building has been draught proofed and mechanical ventilation is in place, but the home does not have another form of air supply, moist (unhealthy) air can be drawn in from the crawl space, which in some areas can even contain radon.

General developments

The installation of supply and discharge ducts in existing homes is a major impediment to the application of balanced ventilation systems with heat recovery. If a new building envelope is installed as part of a home renovation, the supply ducts can be incorporated into the envelope. A suspended ceiling might also be installed. These solutions are not, however, possible or desirable in all cases. A number of parties offer solutions for balanced ventilation with heat recovery in existing buildings, such as different air distribution and decentralised systems in which supply and discharge run through the façade of the living area.

There are parties that can install central balanced ventilation with heat recovery in a home with alternative air distribution that requires fewer ducts. In that case, the clean air is mainly introduced via the stairwell or hallway and enters the rooms through mixing fans under the (shortened) internal doors. In one of the methods that has been developed, the air is discharged only through the standard ducts (kitchen, bathroom, toilet), but air is actively fed into the bedrooms, which in the average home can be accessed easily from the attic (where the balanced ventilation system can be found). In another method, the air is not actively fed into the bedrooms but actively discharged. A disadvantage of such far-reaching changes to the ventilation system is that the work often cannot be carried out by one and the same person or company and involves several different disciplines.

Decentralised ventilation (with heat recovery), where each space is ventilated separately, can offer a favourable solution for high-rise buildings. Decentralised ventilation is in need of further development. As an example, problems with noise still persist in current systems, especially if a demand-controlled system switches on when the resident is asleep. There are new systems on the market that are sufficiently quiet. These systems are easier to use, thereby removing an impediment to the installation of a ventilation system.

It would be interesting if an integral system were to be developed in which heating, cooling and ventilation were incorporated as a single solution – not least because, currently, there are sometimes three displays for thermostat, zoned thermostat for floor heating and ventilation. These systems do not communicate and do not use unified communication protocols. There are gains to be made here in terms of comfort and energy use.

Increasing (system) efficiency and optimising ventilation systems

A ventilation system uses energy, but energy-efficient systems can help to save energy. Air that is fed in from outside needs to be heated during the colder months of the year and cooled in the summer, which costs energy. In the case of demand-controlled mechanical ventilation or balanced ventilation with heat recovery, this energy use can be reduced by 60 to 80 per cent. This is because the quantity and location of the air from outside is controlled with the aid of sensors and actuators, or because the air being fed in is preheated by heat recovery. Non-demand-controlled systems use more energy because they also ventilate when no ventilation is needed. These systems are relatively easy to convert to demand-controlled ventilation systems.

In practice, the electricity consumption by mechanical ventilation systems often seems to be higher than the NTA8800 calculations suggest. In many cases, this is because the ducts have been installed incorrectly (and the resistance is too high) or because the valves have been improperly adjusted and filters have not been changed promptly. Auxiliary energy can then make up a significant proportion of total electricity consumption in the case of natural supply and mechanical discharge as well as for central heat recovery systems. Also, if heat recovery is not properly tuned, the supply and discharge may be unbalanced and thus less efficient. In that case, heat recovery may ultimately cost more electrical energy than it reduces by limiting heat loss and cooling loss when compared to a system without it. Good design and installation are thus crucial to preventing the system from using more energy than is needed. In many cases, there is no check as to whether the system has been installed correctly and is operating properly.

Ventilation systems can also help to cool the home in the summer.[12] Mechanical ventilation systems can create an air flow that brings cool air from outdoors into the house at night. Current balanced ventilation systems have a bypass to prevent the supply of cool air from being pre-heated. In some cases, the user needs to switch this bypass on and off each time. One of the systems on the market has a cooling function on the appliance that automatically increases the flow rate when it is colder outdoors than inside the home.

It is worth noting that the recent rise in energy prices may cause users to deactivate ventilation systems and seal up ventilation grilles to help reduce energy usage and costs.

Reducing purchasing and installation costs

Standard discharge, such as moisture discharge from bathrooms with a sensor or from a kitchen extractor, is neither complicated nor expensive,[13] but after draught proofing, many existing homes also require additional ventilation in other rooms to help maintain high-quality air.

The cost price of a central balanced ventilation system with heat recovery is only around EUR 1000 to 1500, but the design and installation in an existing home is complex, sometimes requires several disciplines and is time-consuming, so the overall cost can come out as high

---

[12] Using windows or special facilities for night-time ventilation enables much larger ventilation flows – in the case of cross-ventilation, a factor of 10 to 100, which can have an improved cooling effect. Please note that cross-ventilation is the opening of windows and doors in two façades with different orientations or different heights.

[13] To ensure compliance with the CE label, many ventilation systems are already fitted with a sensor.

as EUR 6000 to 7500.[14] [15] With a plug-and-play installation method and repeat execution, these costs could be reduced considerably, to no more than EUR 1500. It is important to point out that prices are currently rising rapidly. Another solution is to offer ventilation systems as a service, perhaps for a service life of 10 to 20 years. This way, it is easier to separate the service life from the envelope and installation.

Reducing noise production

There are no noise requirements for ventilation systems in existing buildings.[16] Complaints from residents about noise pollution from ventilation systems are commonplace, which can lead to ventilation systems being deactivated. If a ventilation system has been well designed, however, and properly installed, it should not be audible (even 25 dB should not be a problem, which is a requirement in Switzerland, for example). To prevent noise pollution, it is important that installers are properly trained, systems are easy to install and noise generation is closely monitored. Sound measurement is currently carried out by a specialised firm in many cases. Methods have recently been developed with Binnenklimaat Nederland, TNO and Techniek NL to allow installers and contractors themselves to test noise, airtightness and ventilation flow rates.

Boundary conditions for upscaling

The development of systems in which a flawlessly operating ventilation system can be more easily installed, such as with a plug-and-play installation method, can accelerate the use of ventilation systems in existing homes. It can reduce installation times, reduce installation costs, improve (energy) performance of the system and help to ensure that ventilation is incorporated into renovations as a serious solution.

It is also essential that people are better aware of the importance and benefits of good ventilation. Upscaling takes place primarily because people are familiar with the options. Monitoring and empowering users can play an important role here. If users were to have the means to measure air quality and receive feedback on the operation of the ventilation system, it could help to raise awareness and provide the option to hold clients and installers accountable. Problems with ventilation and their solutions could also be made known with a campaign.

In addition, it is important that choices are not based on the theoretical performance according to the minimum requirements of the Buildings Decree, but on the actual performance of ventilation systems, such as indoor air with minimum health impact, proper comfort with minimum expense and low energy consumption by the ventilation system. As such, it is recommended that ventilation requirements be intensified. The ‘Healthy homes’ programme of requirements provides guidance on this (Binnenklimaat Nederland, 2022). The quality of the indoor air could also become part of a home’s energy label.

---

[14] The aforementioned air distribution systems cost roughly the same or will be slightly cheaper.

[15] By way of comparison, installing a ventilation system in a newly built home costs around EUR 2500 to 5000. Another factor at play here is that, in the case of new buildings, there is ample knowledge of ventilation, while other people work on existing buildings who do not have the same level of knowledge of ventilation systems.

[16] If there had previously been a natural ventilation system in the home that generated no noise, the level obtained by law determines that the minimum noise requirements according to the Buildings Decree apply for new buildings.

Potential market developments

Description

For the potential market developments of ventilation systems, in terms of market share, the assumptions for the market developments for industrial renovation (see the eponymous sub-report) have been followed, with only homes built before 1995 being renovated. In the KEV estimate for 2030, 73 and 75 per cent of all multi-family homes and single-family homes respectively (built before 1995) have natural ventilation. The point of departure for this sub-report is that a ventilation system is used in this proportion of renovated homes once they have been draught proofed. The impacts are thus calculated in relation to a home heated by a natural gas-fired CH boiler, with natural ventilation.

In calculating the impacts, a distinction is drawn between current and innovative technology. The current standard in the case of home renovation is the use of mechanical ventilation. In existing homes, the use of balanced ventilation with heat recovery is a complex process on account of the need to install supply ducts, but innovations such as those outlined in ‘Developments in the technology’ offer solutions to this. In the calculations with the innovative technology, it has thus been assumed that, in single-family homes, balanced ventilation with heat recovery is used via air distribution, and in multi-family homes, balanced ventilation with decentralised ventilation systems is used. It is assumed for all ventilation systems (current and innovative technology), that the system is demand controlled, as this is most beneficial for energy use.

Baseline

In the Baseline in KEV 2021, 35,000 ventilation systems are added between 2020 and 2030 to existing homes built before 1995. This is equivalent to around 1 per cent of the pre-1995 housing stock using a ventilation system.

Doubling

Not included, as the effect is so small in accordance with the Baseline.

Natural opportunity

As outlined in the ‘Industrialisation of renovation concepts’ sub-report, this development assumes that, between 2020 and 2030, 10/50ths of the housing stock will be renovated, equivalent to more than one million homes.

To ensure that ventilation systems are used in these homes, it is important that all affected parties understand the importance of adequate ventilation and that the ventilation system is installed on the basis of appropriate performance requirements. It must be possible to check and enforce proper installation of the system and adherence to the performance requirements. Installation can be simplified with plug-and-play systems.

Technical potential

As outlined in the ‘Industrialisation of renovation concepts’ sub-report, the technical potential is the maximum theoretically achievable potential, whereby it is assumed that all homes built before 1995 will be renovated by 2030. The number of homes renovated in these potential developments is extremely high. This sub-report is thus primarily about demonstrating the impact of so many renovated homes. The same boundary conditions apply here as for ‘Natural opportunity’.

Table G 1 Description of the potential market developments for ventilation systems, the impact of which has been calculated in this sub-report

Potential market developments for ventilation systems	
	Description
Natural opportunity	Assuming that the service life of insulation is 50 years, 10/50ths of the housing stock built before 1995 will be renovated between 2020 and 2030. Of these 10/50ths, 73 and 75 per cent of the number of multi-family homes and single-family homes respectively still have natural ventilation that will be replaced with mechanical ventilation or balanced ventilation with heat recovery.
Technical potential	100 per cent of the homes built before 1995 will have been renovated by 2030. Of these, 73 and 75 per cent of the number of multi-family homes and single-family homes respectively still have natural ventilation that will be replaced with mechanical ventilation or balanced ventilation with heat recovery.
	Boundary conditions
Natural opportunity/ Technical potential	- Awareness of the importance of good ventilation - Steering based on (sharper) performance requirements and proper monitoring - Plug-and-play installation systems

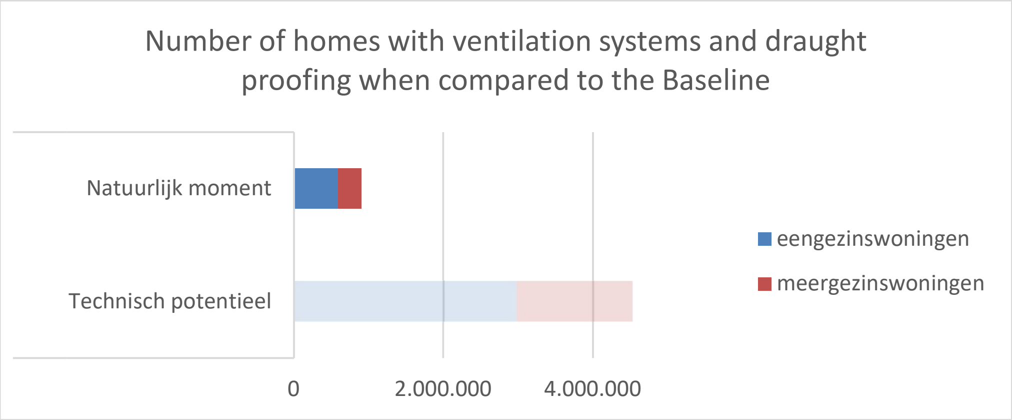


Figure G 1 The number of existing homes (built before 1995) in 2030 when compared to the Baseline that use ventilation systems and draught proofing in different potential market developments.

Requisite innovations

According to experts, an important innovation in the use of ventilation systems is the development of good plug-and-play installation systems for all conceivable situations in homes. It can reduce installation times, reduce installation costs, improve performance of the system and help to ensure that ventilation is incorporated into renovations as a serious option. It is important that operation of the ventilation system can be monitored.

Impact

This section calculates the potential impact of a sub-topic for different market developments. This section focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. This means that other impacts of higher market share or of an innovation, such as improved health, are not taken into consideration.

CO_2 emissions reduction

The following emissions were included in the calculation of CO_2 emissions from ventilation systems:

- (Indirect) emissions from electricity use
- (Direct) emissions from use of natural gas to pre-heat incoming ventilation air
- Avoided (direct) emissions due to reduced heat loss through draught proofing

The heat recovery system in balanced ventilation prevents 70 per cent of the heat loss from mechanical ventilation, thereby reducing CO_2 emissions, even though heat recovery uses more electricity. It has also been assumed that balanced ventilation systems in single and multi-family homes (air distribution and decentralised ventilation) save the same amount of CO_2 proportionally. The assumptions and figures used are explained in further detail in Annex F.

The result at a natural opportunity is 0.09 Mt CO_2 reduction for mechanical ventilation ('current technology') and draught proofing. The result for the same market development is a 0.15 Mt reduction for balanced ventilation with heat recovery ('innovative technology') and draught proofing.

The results show that balanced ventilation with heat recovery in single-family homes gives rise to 1.5 times more annual net CO_2 reduction than mechanical ventilation (Figure). The figure is 3.4 times as high for multi-family homes. The ratio by home type is different because, in the case of multi-family homes, in view of the smaller home, there is less of a saving from draught proofing, but the same increase in CO_2 emissions from the ventilation system.

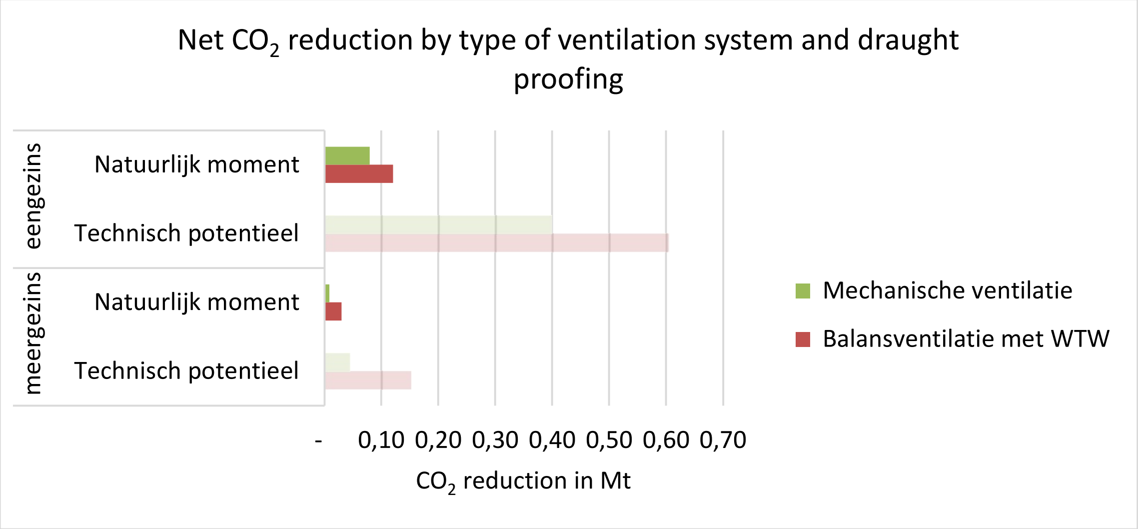


Figure G 2 Net CO_2 emissions reduction (in Mt) in 2030 when compared to natural ventilation for the potential market developments.

Additional national costs

The (additional) costs for mechanical and balanced ventilation when compared to natural ventilation comprise:

- Investment costs for the ventilation system
- Annual maintenance costs for the ventilation system
- The change in annual energy costs

The change in energy costs when compared to natural ventilation is a combination of:

- Reduced heating costs on account of reduced heat loss after draught proofing
- Increased electricity costs from ventilation
- Heating costs to pre-heat the incoming ventilation air flow minus any reduction through heat recovery

The national costs for draught proofing comprise the investment costs minus the saving on energy costs from draught proofing. The investment costs for ventilation systems and draught proofing have been taken from the Arcadis cost figures (Arcadis, 2020), whereby it was assumed for air distribution that the costs are equal to those for a standard balanced ventilation system with heat recovery, as indicated in the interviews with experts.

The results show that mechanical ventilation has higher national costs when compared to balanced ventilation (Figure). For the natural opportunity, the national (additional) costs for homes are EUR 0.4 billion per year for mechanical ventilation, EUR 0.3 billion per year for balanced ventilation with heat recovery and EUR -0.01 billion per year for draught proofing.

This difference is due to balanced ventilation being more expensive, while yielding a higher reduction in natural gas use due to heat recovery, which ultimately brings national costs to a lower point than for mechanical ventilation. It is also clear that draught proofing gives a slightly negative national cost. Draught proofing comes out favourably, as the annual investment is extremely limited and the annual saving on heating costs is only slightly more. Taking the average for homes built before 1995, draught proofing can yield a significant saving on heating costs.

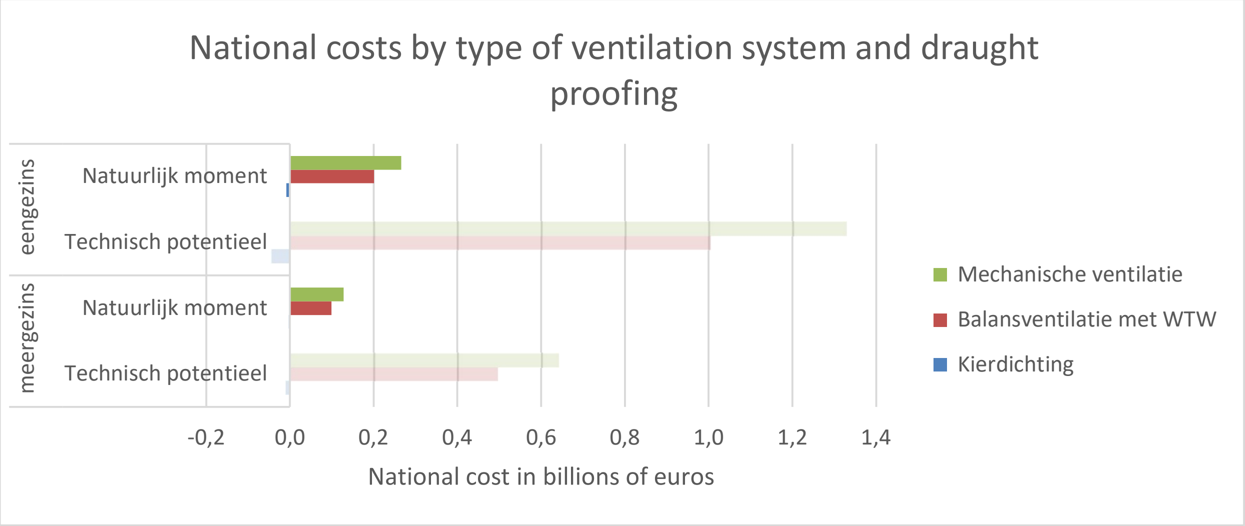


Figure G 3 Additional costs (billions of euros per year) in 2030 when compared to natural ventilation for the potential market developments.

Summary

In the case of renovation, homes are often draught proofed, thereby limiting the natural supply of fresh air and having an impact on air quality. Ventilation systems with demand control can supply the requisite ventilation and prevent unnecessary (cold) air from being introduced into homes that need to be heated during the heating season. In the event that, according to the technical potential, draught proofing with demand-controlled mechanical ventilation is used in all renovated homes, CO_2 emissions can be reduced by 0.09 Mt and by 0.15 Mt with demand-controlled balanced ventilation with heat recovery. Balanced ventilation with heat recovery, at EUR 0.3 billion in national costs, is slightly cheaper than mechanical ventilation, at EUR 0.4 billion, as the heat recovery system provides greater energy saving.

Attention needs to be drawn to the importance and the benefits of proper ventilation, and steering needs to be based on performance requirements, which may be intensified. Monitoring of the air quality and operation of the ventilation system can help improve awareness and offer insight into performance.

Renovated homes often use (demand-controlled) mechanical ventilation. Further development of plug-and-play installation systems and innovations, such as decentralised ventilation systems and air distribution methods, is needed to simplify the implementation of balanced ventilation systems with heat recovery in existing homes. A plug-and-play method can also improve the performance of the system by minimising the possibility of errors during installation.

H. Sub-report – small-scale heat storage

Introduction

Context

Heat storage has the potential to contribute considerably to the energy transition. By storing energy (in the form of heat or electricity) as heat for later use during times of surplus, sustainable sources can be more effectively utilised, congestion in the electricity grid can be prevented and additional (fossil) power plants to cover peak demand can be avoided. The Compact Conversion and Storage (CCO) Roadmap was published in 2016 by the MJP CCO consortium, with the aim to further develop storage technology.

It is possible to distinguish between several different heat storage technologies:

- Sensible heat (Thermal Energy Storage (TES)) in water (usually temperatures between 0 and 100°C)
- Sensible heat storage in liquid salt, oil, sand, stone, ceramics (usually temperatures between 100 and 1000°C)
- Latent heat storage in phase-changing materials (PCMs)
- Heat storage in thermochemical materials (TCMs)
- Heat storage through redox reactions

Only sensible heat storage in water is currently used on a large scale (larger than building level), such as in shallow/deep aquifers, mines, wells and water tanks. TKI UE has defined the trend: ‘Large-scale (heat) storage is having difficulties in being implemented’. In the MMIP, TKI UE outlines the following points for attention when it comes to upscaling heat storage:

- Reducing purchasing and installation costs and operation
- Increasing (system) efficiency and optimising heat storage systems
- Improving the integration of domestic heat storage systems into (renovation concepts for) existing buildings
- Further developing control systems for small-scale heat storage systems and the ability to provide flexibility to the electricity or district heating grid
- Further developing circular concepts for small-scale heat storage systems
- Specific points for attention for the further development of TCM concepts

Scope

In this sub-report, we focus on small-scale (at home level) heat storage. Large-scale (multiple homes) heat storage will be covered in sub-report J.

Reading guide

This sub-report contains only a qualitative section, which comprises the ‘developments in the technology’ and ‘boundary conditions for upscaling’ sections and is based on desk research and an interview with Ruud Cuypers (TNO). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to this interview. This sub-report does not include a quantitative impact calculation. The sub-report concludes with a summary of the insights.

Developments in the technology

Summary of interview with Ruud Cuypers (TNO)

General

Sensible heat

Sensible heat storage in water (with or without vacuum insulation technology) has been fully developed and is available on the market, including for existing buildings, if the requisite space is available (for around 200 litres). This technology is suitable for daily heat storage, a maximum of two days, as it loses heat quickly.

In addition, Borg has also developed a system to store heat under the garden instead of inside the house, which may be appealing on account of its spatial integration. NES has developed a boiler with very low losses, which means that heat can be retained for longer or may allow heat to be stored at a higher temperature. Both technologies are in their pilot phase.

PCM

Phase-changing materials (PCMs) are an interesting technology that could also be used in construction materials. Once the PCMs liquefy, they need to be actively cooled so that they solidify, which places significant demands on practical usability. The market also offers a combination of sensible heat storage in water and salt as PCMs.

TCM

An interesting aspect of storage in thermochemical materials (TCM) is that these materials can store heat without loss by using a chemical reaction between salt and water. A minimum temperature is needed for the reaction, which is currently 80°C for the salt reaction used. In the case of low-temperature heating in the home, this temperature is not readily available. It could be reached directly with electricity, with solar collectors or with a high-temperature heat pump. An alternative material whereby the reaction works at a lower temperature could also be considered, but with the drawback of lower storage density.

An appliance is also in development based on potassium carbonate at atmospheric pressure, currently in TRL[17] phase 5-6. The current pilot phase is focused on demonstrating that the energy put in also comes out and that the requisite temperatures are achieved.

TNO is working on a TCM vacuum system with sodium sulphide that has already been demonstrated in the laboratory and in a controlled test environment at the desired scale. To advance this technology, three steps need to be taken:

1. The technology needs to be tested in real-time situations amongst early adopters (pilot).
2. The production of appliances must be series production rather than unit production in order to lower costs.
3. It must be demonstrated that it is safe to use (e.g. with certificates), as it is a vacuum system and as it works with the toxic substance sodium sulphide.

Increasing (system) efficiency and optimising heat storage systems

---

[17] The Technology Readiness Level (TRL) is a measure to indicate the stage of development of a new technology. Phase 1 is the most basic level, and in phase 9, the technology is demonstrated in a practical environment.

Heat storage provides additional utilisation of renewable energy that could not otherwise be used effectively *(curtailment*). There are, however, heat losses during storage and/or when charging/discharging. In the case of sensible storage and PCM, the loss is dependent on size, temperature, control and use. A TCM system loses no heat during storage, but it does lose heat during charging/discharging.

Heat storage in water can be used effectively to capture daily fluctuations; TCM is more suitable for storage of a few days to several weeks.

Reducing purchasing and installation costs and operation

Sensible storage in water is fairly simple and relatively inexpensive, but heat loss is high.

TCM is relatively more expensive, as it is a more complex appliance than sensible heat storage and as the heat exchanger is, for now at least, made of copper. An aluminium heat exchanger and series production could help to reduce costs.

Another way of looking at this is to take the costs of grid reinforcement as a point of departure; these have been estimated at EUR 12,500 per household up to 2050 (CE Delft). If this reinforcement can be partially avoided with heat storage, it would create financial benefits that should be included in the business case for its use. The amortisation opportunity must then rest with the parties that are required to invest (particularly homeowners, housing associations, landlords) and not only those who benefit (such as the network operator). To make this possible, the law will need to be changed.

Small-scale heat storage can be expensive and is not yet commonplace. The need for storage offers hardly any financial incentive, while it can help to reduce costs by reducing the peak load on the district heating grid or electricity grid in other places, thereby eliminating the costs for reinforcement.

Use of space: integration of heat storage systems into homes

A hot water boiler has a storage capacity of 0.07 GJ/m^3. The TCM currently has a capacity of 0.35 GJ/m^3 (with prospects for a further improvement of 1.5) (both incl. insulation material). Until fairly recently, increasing the storage density for heat storage and thus reducing use of space was the principal goal. Linked with congestion management, attention is now shifting from use of space to the speed at which the battery can be (dis)charged. This depends on the capacity. A new additional KPI could therefore be the capacity of the heat battery.

Innovation technologies, such as PCM and TCM, have a higher energy density and can save space when compared to storage with equal heat quantity in a water buffer.

Boundary conditions for upscaling

Boundary conditions for further upscaling of heat storage technology in general are related to the development of technology and increased demand for heat storage. As outlined above, a number of technologies are not yet advanced enough to be marketed. Investment or grants are needed to allow these developments to be advanced further. There are fewer and fewer grant schemes to enable the requisite low-TRL**Error! Bookmark not defined.** level activities to be carried out for further development. When it comes to TCM, the intention is to develop a new Compact Conversion and Storage roadmap.

For further development, it is crucial that users familiarise themselves with and become interested in heat storage. They must be able to understand that heat storage is beneficial from both an energy and economic perspective, thus allowing them to utilise any surplus from their own PV generation. For the time being, there is no urgency when it comes to heat storage, in part because the security of supply from the electricity grid is high and many alternative energy technologies are more expensive.

Summary

Heat storage can contribute to the energy transition by making better use of renewable energy sources, thereby avoiding the use of natural gas in auxiliary boilers at times of peak demand and relieving the electricity grid. These benefits of heat storage are not yet always recognised and appreciated, however, which means that the costs and benefits do not always rest with the same party and there is no business case.

According to the experts interviewed, in addition to a greater incentive to store heat, consistency in policy rules and permit conditions as well as standard testing frameworks are boundary conditions for upscaling. In addition, innovative storage technologies, such as high-temperature storage (HTO), thermochemical materials (TCMs) and phase-changing materials (PCMs), can also offer new solutions for more efficient and more compact heat storage that is more cost effective in the long term. PCMs are now being launched onto the market, but HTO and TCMs require further development.

I. Sub-report – district heating grids

Introduction

Context

In the Climate Agreement, it was agreed that 750,000 existing homes should be connected to a district heating grid by 2030. This sub-report focuses on low-temperature (LT) grids, as they offer several advantages over medium-temperature (MT) and high-temperature (HT) grids:

- The ability to tap more renewable resources
- Improved energy efficiency due to reduced heat loss and better COP of the heat pump (which also takes the strain from the electricity grid)
- It offers more opportunities for combination with large-scale heat storage and thus flexibility on the electricity grid
- Option for cooling alongside heating

The trend as defined by TKI UE relating to (very) LT grids is: ‘the share of district heating grids with lower temperatures and fifth-generation principles remains low’. In the MMIP, TKI UE outlines the following points for attention when it comes to (all types of) district heating grid(s):

- Further developing citizen participation and (open) governance models
- Further developing district heating grids that also supply cold
- Optimising and reducing the cost of installation methods and reducing local nuisance when installing district heating grids
- Reducing the use of space and improving the appearance of above-ground and underground components
- Improving (system) efficiency by:
    - Developing more efficient infrastructure and maintenance
    - Optimising configurations for heat and cold grids
- Further developing heat-grid systems with more flexibility potential
- Further developing selection tools, design processes and roll-out models for heat and cold grids
- Further developing specific strategies to mitigate saturation risk
- Continuing development of circular concepts for heat-grid systems

Reading guide

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ sections and is based on desk research and interviews with Louis Hiddes (2RC, former founder of Mijnwater BV), Martijn Clarijs (TNO) and Ivo Pothof (Deltares). The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised. The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Combined summary of the interviews with Louis Hiddes (2RC, former founder of Mijnwater BV), Martijn Clarijs (TNO) and Ivo Pothof (Deltares)

The traditional district heating grids currently installed in the Netherlands are primarily high-temperature (>75°C) and medium-temperature (55-75°C) grids powered by natural gas, residual heat, geothermal and biomass. With these types of grids, there is a constant supply of heat, so in addition to distribution losses, no demand also means a loss of heat. In addition, there are also ‘source grids’ or very low-temperature grids (<30°C) that use low-temperature (LT) heat (such as TES, aquathermal and (ground) heat exchangers). This LT heat is raised to 70°C by a central heat pump or to 45 to 60°C by individual heat pumps. There is currently much talk of low-temperature (LT) grids (30 to 55°C), but hardly any are currently installed, and those that are installed are mostly for new buildings.

The new generation (fifth generation) of district heating grids are exchange grids for heat and cold, whereby customer demand activates the system, multiple energy sources can be used, thermal buffers are used, cooling can also be offered and variable heating lines can be used. Connection to the electricity grid and supply of flexibility to the grid are also foreseen for these fifth-generation grids.

An important step, however, is to acquire more experience with the installation of low-temperature grids. This sub-report focuses on the benefits of low-temperature grids and the bottlenecks to upscaling. Instead of LT grids, the current trend is actually moving towards district heating grids of at least 70 degrees. This is the most practical solution from the perspective of heat companies, as this temperature is also suitable for supplying domestic hot water, and in many cases, no modifications to the home are needed. Heat companies also fear a loss of comfort in existing homes due to a lack of experience and lack of familiarity with low-temperature heating. Recent research in the WarmingUP programme, however, has demonstrated that 60 per cent of homes are now LT-ready and can be heated at low temperature without any modifications (Pothof, Vreeken, & Meerkerk, 2022).[18] In addition, there are also a number of initiatives[19] in place to renovate homes to the ‘Standard’ so that they are largely LT-ready. Providing domestic hot water with a separate installation remains a point for attention when it comes to low-temperature heating.

Incorporating LT grids into considerations for heating strategies as a full-fledged solution also creates opportunities to capitalise on the benefits of low-temperature heating, such as improved energy efficiency, improved exploitation of renewable LT sources, stability through the use of multiple sources and the option for cooling. An LT grid requires an integrated view in which the heat source is not the point of departure and does not stop at the point of heat supply into the home but takes comfort and low energy costs as the point of departure, is integrated with the electricity grid and connects heat and cold from buildings together. This also requires a vision for the future in which, for example, cooling becomes necessary with increasing heating of homes and all homes become LT-ready in the decades to come. It also

---

[18] This study also shows that 95 per cent of homes are MT-ready.

[19] In the Netherlands, it has already been agreed that, by 2050, all rental homes must comply with the ‘Standard’, which means they will be insulated to a high enough standard that they no longer need natural gas; requirements on buildings are also being discussed at European level. A manifesto was signed for ‘LT-ready as an integral requirement for improving building sustainability’ at the TKI UE congress ‘Klaar voor lager’.

includes a thorough building analysis in the respective area, with an investigation of issues such as:

- What is the current energy demand of the buildings and what design capacity for heating is sufficient?
- To what extent can energy demand be further reduced/can a building be optimised? Consultants are needed for business premises, for example, who can also propose recommendations on energy savings and usage for specific business processes that go beyond general suggestions, such as LED lighting and solar panels.
- Does this then create a (further) energy surplus, such as waste heat, and if so, where could this energy be put to use? A great deal of energy is still wasted because thorough analysis of LT sources in the area (at business level) is often lacking.

Further development of citizen participation and (open) governance models & further development of selection tools, design processes and roll-out models for heat and cold grids

It is essential that local authorities assume a leadership role in the roll-out of district heating grids. They have the ability to represent multiple interests and can eliminate or minimise uncertainties.[20] However, significant differences in the level of knowledge between local authorities are noted. Housing associations, moreover, often lack sufficient knowledge of district heating grids and as a consequence are anxious about loss of comfort. A number of examples exist whereby, for this very reason, housing associations demand supply temperatures of 90 degrees in the installation of district heating grids. Demonstrations of properly functioning, low-temperature grids in existing buildings and the dissemination of existing knowledge can help to ensure the requisite level of confidence. In addition, a thorough approach for calculating heat variants in low-temperature use and for reaching decisions could help provide support to local authorities and housing associations.

In addition, knowledge is still needed of the best strategy for installing LT district heating grids. For example, is it a sensible idea to start with small-scale district heating grids and to continue to expand them, or to allow multiple small district heating grids to exist alongside one another? What are the benefits and drawbacks of a strategy of offering medium temperature in a district heating grid first and then switching to low temperature at a later stage?

There is a lack of confidence in the comfort of low-temperature heating, and the parties that ought to assume a leadership role do not always have the requisite level of knowledge. Demonstration projects, provision of information and a reliable tool for calculating heat variants at low(er) temperatures can provide support to the decision-making process to arrive at a low-temperature heat supply.

Reducing the use of space and improving the appearance of above-ground and underground components

From a physical perspective, a larger diameter of pipeline would be needed to allow the same calorific content to be transported if there is a smaller difference in temperature. However, if different points of departure are used than for MT grids, LT grids will not need a larger diameter. As an example, current district heating grids are dimensioned for peak demand, such as between 7 and 9 in the morning. *Peak shaving*, where less night-time reduction is applied, could knock 20 per cent off the peak load. Heat companies are somewhat reluctant

---

[20] In autumn 2022, the government announced that district heating grids will largely come under public ownership.

to adopt this principle, however, as it requires behavioural change amongst users. They are currently accustomed to lowering the thermostat at night, which is not ideal when working with an LT grid. In addition, LT grids have around 40 per cent less heat loss than MT grids, which also means that the diameter increase could be limited. Finally, with low-temperature grids, the distance to main water pipelines needs to be less than with MT or HT grids, which is beneficial for use of space underground.

Finally, the use of thermal buffers at multiple locations in an LT district heating grid is an important key to reducing peak demand. With intelligent system control, a heat supply will already be there, close to the point at which (in the more commonplace situations) the heat is required. Taking this into consideration will help to further limit the diameters in a grid.

When using future points of departure that are appropriate to LT grids, there is no need for the pipes in an LT grid to be any larger than their equivalents in an MT grid.

Increasing (system) efficiency by developing more efficient infrastructure and maintenance

The efficiency of a district heating grid is in part determined by the heat loss in the pipes, the pump energy and the additional energy that needs to be added to the grid to upgrade the heat or to satisfy peak demand.

The closer the temperature in the pipe is to the temperature in the ground, the less the heat loss during transport and distribution. A key figure for heat loss in an MT grid is 25 per cent of heat production – in an LT grid, it is 15 per cent, i.e. 40 per cent less than in an MT grid. Greater heat demand is transported in an MT grid due to the supply of domestic hot water. There is considerable demand for space heating for around six months of the year. If domestic hot water is also supplied over the HT or MT district heating grid, hot water (at a temperature of at least 70 degrees at the extremity of the district heating grid) should flow through the pipes throughout the year, with hot water withdrawn only around 3 to 4 per cent of the time (85 to 90 per cent of that figure between 7 and 9 in the morning). This means considerable heat loss in the pipes and continuous use of pump energy.

Upgrading heat is not always necessary in an LT grid. In many cases, the heat (or cold) from the grid can be used directly for customers. In the event that upgrading the heat is necessary, the most appropriate solution is to use a collective (industrial) heat pump for apartment complexes and to use individual heat pumps for single-family homes.

In an LT grid, less heat is lost during transport than in an MT grid, as the difference in temperature between the pipes and the ground is less and heat does not need to be supplied throughout the year to meet demand for domestic hot water. Upgrading heat with a heat pump for space heating is not always necessary in an LT grid.

Optimising and reducing the cost of installation methods and reducing local nuisance when installing district heating grids

Sizing the district heating grid to meet peak demand increases the cost (both CAPEX and OPEX) and reduces energy efficiency. In addition to use of *peak shaving* as referred to above, the remaining peak demand can (in part) be met by buffering (stored heat) rather than generating heat using fossil energy (see also the ‘Large-scale heat storage’ sub-report). If the supply profile is flatter, the costs can be reduced by tens of percentage points on account of narrower pipelines, transport pumps that have to work less hard and a more predictable supply profile. An example if a different point of departure is adopted can be found in the WarmingUP project on ‘Reduced supply temperatures’ in which, on the design day, it must be possible to supply the heat demanded for space heating within 18 hours. That leaves ample time during the day for heat to be stored in a hot water tank, giving rise to significantly reduced peak demand compared to conventional points of departure.

In the case of pipes with the same diameter, the difference in infrastructure costs between a grid at 50 or 70 degrees is minimal. Pipes in an LT grid can be made of plastic rather than the steel used in MT and HT grids. Material costs for plastic are higher, but the costs for installation are lower, as welded connections in plastic are much cheaper to produce. The quality requirements for steel pipes are already well defined, while those for plastic pipes are still being developed.

If modifications in the home are still needed for LT heat to be used to heat the home, an investment will be needed. The pursuit of reduced energy demand from the home and improved comfort and indoor climate can, however, also be viewed as a favourable development that is separate from low-temperature heating.

When it comes to operating costs (OPEX), low-temperature heat may involve additional costs to upgrade the heat with a heat pump (central or decentralised) that would not be incurred with an MT grid. Looked at it differently, an LT grid has reduced heat loss, which can give rise to lower OPEX costs than an MT grid.

In addition to the CAPEX and OPEX, the interest rate and the amortisation period are also important when it comes to financing. If a longer service life[21] can be relied upon, or if parties can borrow money with longer amortisation periods or at lower interest rates, financing solutions could be affected. The efficiency that the operator wishes to achieve is also an important factor.

In addition, the business case put together by a heat company often takes only the heat supply into consideration, although it should also include the cold supply. Homes now have to contend with ever increasing indoor temperatures on account of climate change, which means that cooling has an important role to play alongside heating. Home cooling in the Netherlands is not yet a standard feature and is thus seen as additional comfort, with no monetary value yet attributed to cooling. LT grids emerge more favourably in the trade-off between heat strategies if cold supply is considered as value added and the acquisition of an air-conditioning system as the alternative is incorporated into the business case with end-user charges. Supplying cold will not only help save on the costs of air-conditioning but potentially also on the costs of reinforcing the electricity grid.

In a nutshell, a good business case for a district heating grid requires inclusion of all costs and benefits incurred/experienced by the parties involved, now and in the future. In addition, it is not solely about supplying heat as cheaply as possible, but also about ‘harvesting’ and being able to use (residual) heat and cold at various points in the built environment. Finally, good customer service and security of supply are both important, as unsatisfied customers mean higher costs.

The LCOE costs for an LT grid do not need to be higher than for an MT grid. Important aspects that play a role in the costs and financing are:

---

[21] The service life is calculated as the (weighted) average service life of all assets in the system.

- ***Preventing sizing based on peak demand through peak shaving and buffering.***
- ***The extent to which homes should be made suitable for low-temperature heating. Many homes are already LT-ready, so this relates primarily to costs for installation for domestic hot water.***
- ***The extent to which an additional collective or decentralised heat pump is required to upgrade the heat for space heating.***
- ***Whether cold supply is incorporated into the scope of the business case alongside the heat supply.***
- ***The interest rates, amortisation periods and*** efficiency ***used for calculation in the business case.***

Boundary conditions for upscaling

Firstly, it is important that knowledge about LT grids is disseminated and that successful demonstrations are given in existing districts as means of establishing confidence in low-temperature heating.

In addition, it is also crucial that local authorities assume a leadership role in the upscaling of LT district heating grids and formulate a future vision for both heat and cold. It is important that they take an integrated view with the quality of life/comfort of residents as the point of departure, the context of the future as a starting point and a thorough analysis of the district as a basis. A sound consideration framework and a calculation model for heat strategies, in which heat and cold can be 'harvested' and supplied, could support local authorities in assuming that leadership role.

To round out the business case, it is important to include the national costs and to adopt other, future-proof points of departure than for MT grids – such as ceasing to size based on traditional peak demand with a considerable amount of night-time reduction. In addition to heat supply, cold supply also needs to be incorporated into the business case, as cooling will play an important role in the future and LT grids can add value in this area.

Finally, domestic hot water supply is an important point for attention. Developing practical solutions for domestic hot water is an important condition for the upscaling of LT grids (see the 'Domestic hot water systems' sub-report).

Potential market developments

In this case, potential market developments are expressed as the number of homes connected to a district heating grid in 2030, under the condition that the home was not already connected in 2020. As such, we are looking solely at homes that were already built in 2020 ('existing' homes). We assume that there is a greater likelihood of homes in densely built areas being connected to a district heating grid than homes in areas with low building density. Here, we use three building density classes. To this end, the heat demand density (for space heating and domestic hot water) per hectare (GJ/ha/year) for each district was used according to the data in the *Startanalyse* (starting analysis) from PBL. Based on the range, we defined three heat demand density classes, with 'Low' being <500 GJ/ha/year, 'Medium' being 500 to 1000 GJ/ha/year and 'High' being >1500 GJ/ha/year. We then determined the number of homes within each of these classes (see Figure I 1 and Annex D).

The following is a description of the potential market developments for district heating grids with corresponding boundary conditions and a summary in the table below. These developments are not intended to be real-life scenarios but are meant to provide an idea of the impacts in different ranges.

Description

Baseline

For the Baseline, the starting assumption was the number of homes assumed to be connected to a district heating grid in 2030 in the KEV 2021 under the adopted and intended policies. In 2020, there were 426,000 homes connected to a district heating grid (at all temperature levels); in the KEV estimate, this rises to 694,000 homes by 2030, an additional 269,000 in ten years. This figure also includes newly built homes that are to be connected to a district heating grid. For existing buildings, this means an increase of 84,000 homes between 2020 and 2030. This is insufficient to meet the target in the Climate Agreement – a growth of 750,000 new connections in existing buildings by 2030.

Doubling

In this potential development, we assume a doubling of the increase in the Baseline for existing buildings. With doubling, or an additional 84,000 homes connected to a district heating grid, the total connected existing homes would be 510,000 by 2030.

Technical potential

With regard to the technical potential, we apply the assumption that 100 per cent of existing homes located within an area classed as having a building density of high or medium will be connected to the district heating grid by 2030. That is more than 6,000,000 homes. As stated above, this is in no way intended as a prediction, but to give an indication of the theoretical range.

Table I 1 Description of potential market developments for district heating grids

Potential market developments for district heating grids	
	Description
Doubling	Doubling when compared to the Baseline of the number of existing homes connected to a district heating grid by 2030
Technical potential	All existing homes in an area with a heat density class of high or medium connected to a district heating grid by 2030
	Boundary conditions
Doubling/technical potential	- Confidence in the supply of comfort from LT district heating grids - Local authorities and housing associations assume a leadership role and take an integrated, future-oriented view - Parties can use a robust consideration framework - There is an incentive and a favourable business case

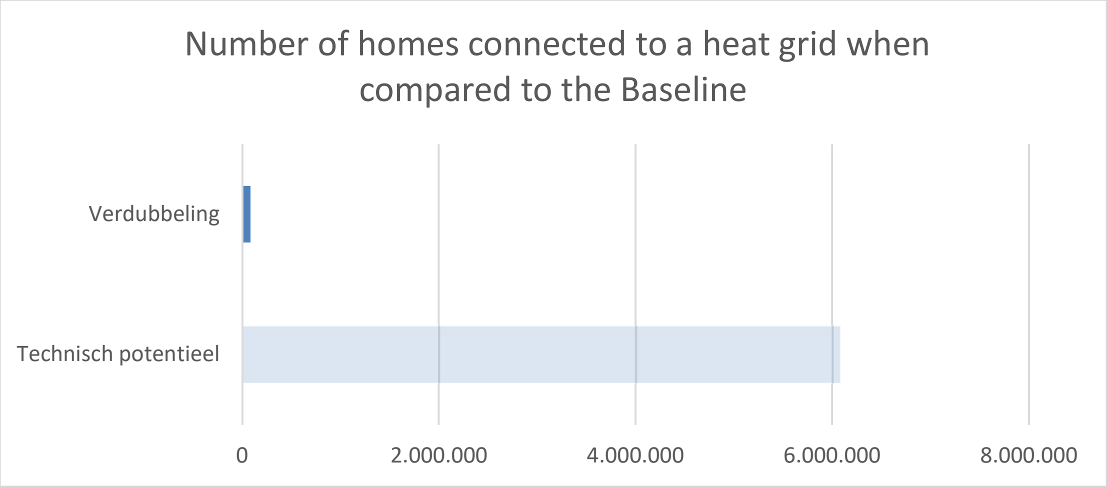


Figure I 1 The number of additional existing homes in 2030 when compared to the Baseline that are connected to a district heating grid in different potential market developments.

Requisite innovations

According to the experts interviewed, the primary bottleneck for upscaling LT grids is the lack of confidence in the supply of comfort and the lack of knowledge amongst some parties who ought to take the initiative. An innovation that could support these parties is the development of a tool that allows different heat strategies to be calculated for a local situation. They could also benefit from a thorough approach to decision-making.

For a more favourable business case, the costs for LT grids could be reduced by preventing peak demand, such as with heat storage, an area in which developments are still needed (see the eponymous sub-report).

Impact

This section calculates the potential impact of a sub-topic for different market developments. This section focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. Other impacts of a higher market share or innovations, such as more potential for the connection of different heat sources and the possibility of cooling, are not taken into consideration here.

In the impact calculations, we draw a distinction between the impact of increased market share with ‘current’ technology and with ‘innovative’ technology. The type of district heating grid to which most existing homes are currently connected is an MT or HT grid. Current technology thus refers to connection to an MT grid. Innovative technology in this sub-report refers to connecting existing homes to an LT grid, which is not currently commonplace (see also ‘Developments in the technology’). In the comparison, we assume the same number of homes connected to an MT or LT grid, while the reference situation is the HR boiler. The costs and benefits of cold supply are not taken into consideration in the calculation.

CO_2 emissions

The direct CO_2 reduction from switching from natural gas to the primary MT heat source was firstly taken into consideration for the net CO_2 reduction in the case of an MT grid when compared to HR boilers. The point of departure is a residual heat source at medium temperature. It has been assumed that heat production from the residual heat source is not free of CO_2; 8.8 kg of CO_2/GJ of heat has been calculated (CO2-emissiefactoren, 2022). Further explanation of CO_2 reductions from different heat sources can be found in Annex D. In addition, the additional CO_2 emissions from the use of auxiliary boilers (12 kg CO_2/GJ of heat) have also been taken into consideration. Considering that MT sources and auxiliary boilers are not CO_2-free heat sources, the CO_2 emissions per GJ have been determined as associated with the heat production. Here, it has been assumed that, based on the interviews, the total pipe loss in the grid is 25 per cent.

In the MT-grid configuration, it has furthermore been assumed that domestic hot water is directly supplied with heat from the main heat source or auxiliary boilers. The temperature of the heat does not, therefore, need to be upgraded first, which means no heat pump is needed. This is possible if the supply temperature is a minimum of 60 degrees. Examples of heat sources that can meet this requirement are residual heat and biomass.

CO_2 reduction from switching from natural gas to the primary LT heat source was taken into consideration for the net CO_2 reduction in the case of an LT grid when compared to HR boilers. It has been assumed that heat production from the LT source is entirely free of CO_2. This could include aquathermal or low-temperature residual heat. There are no auxiliary boilers in this heating system.

The pipe loss is lower than in the case of MT grids – the point of departure here is 15 per cent heat loss, based on the interviews. In the case of LT grids, however, pipe loss has no impact on CO_2 reduction, as there are no CO_2 emissions from the main heat source, and there are no auxiliary boilers.

Another point of departure is the assumption that LT grids use an individual system for domestic hot water. Domestic hot water can, for example, be provided by a booster heat pump, an instant water heater (in the form of an electric geyser) or an electrical boiler. The interviews show that, in practice, the instant water heater is chosen most, in some cases because of the lower investment costs when compared to a booster heat pump, but also because of the higher efficiency when compared to an electrical boiler. The point of departure for the LT grid is thus the assumption that domestic hot water is heated by an instant water heater. This system does produce indirect CO_2 emissions, but consumption by the system may be as much as 40 per cent[22] lower than for an electrical boiler (which has an average efficiency of 95 per cent based on (CE Delft, 2021)). Indirect emissions from electricity demand for domestic hot water have been calculated on the basis of the emissions figures for electricity generation in 2030 on the basis of the KEV 2021 (see Annex D).

Figure I 3 visualises the results for CO_2 emissions reductions from district heating grids. A doubling of the number of existing homes that are connected to a district heating grid yields very little in terms of CO_2 emissions reduction, as the KEV assumes that primarily newly built homes are connected to a district heating grid.

The technical potential gives total net CO_2 reductions for MT grids of 6.0 Mt. The figure is higher for LT grids, at 10.3 Mt. The additional CO_2 reduction in the case of LT grids can be attributed to the additional emissions from the MT source when compared to the LT source (+1.7 Mt), the additional emissions from auxiliary boilers (+2.3 Mt), the additional emissions from pipe loss in the case of MT grids (+1.0 Mt) and indirect CO_2 emissions for domestic hot water in the case of LT grids (-0.6 Mt). The result in the case of MT grids is an overall

---

[22] https://www.duurzaambouwloket.nl/maatregel/doorstroomboiler

reduction in CO_2 of 55 per cent when compared to CH boilers. In the case of LT grids, the figure could be as high as 94 per cent.

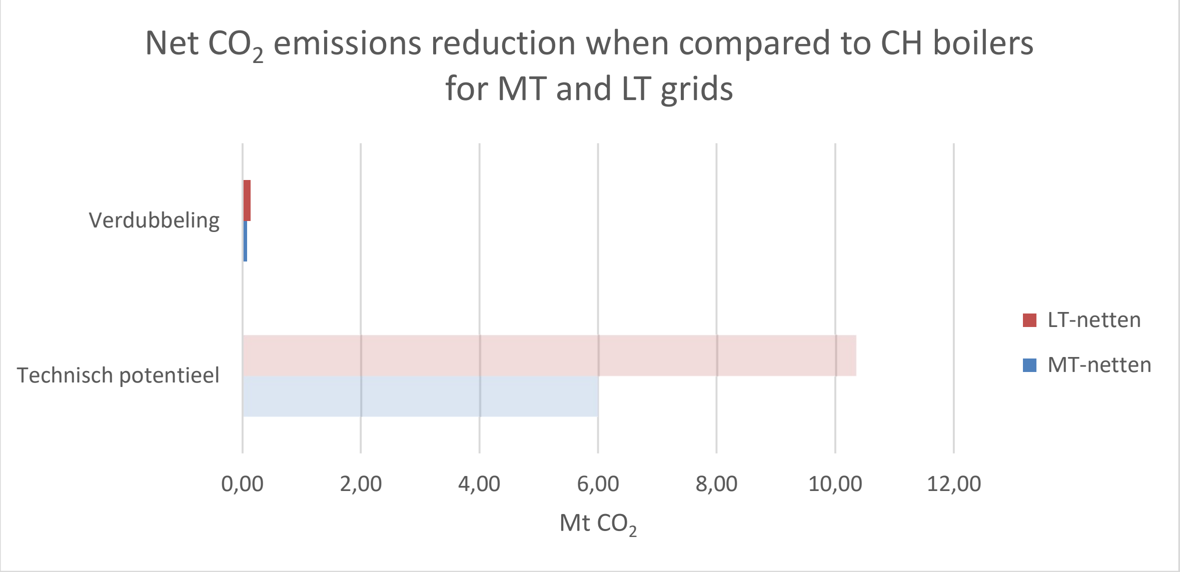


Figure I 2 Net CO_2 emissions reduction (in Mt) by 2030 when compared to CH boilers for MT grids and LT grids in the case of two potential market developments.

Additional national costs

The system boundaries must firstly be determined before determining the national costs of MT and LT district heating grids. Our assumptions are based on the cost components for MT district heating grids included in the *Startanalyse* by PBL. The system costs – from the heat source to the connection in the home – have been divided by the number of connected homes to determine the average cost per home. Only the system costs for the district heating grid and for the connected homes are included (please note that this thus excludes the system costs for the connected non-residential buildings). No insulation costs have been taken into consideration in this system comparison. It has been assumed that the homes will be LT-ready at the time at which they are connected or independently renovated to the level of insulation in accordance with the ‘Standard’ (RVO, 2022). This is an insulation standard that indicates when a home is sufficiently insulated to be free of natural gas.

The average investment costs for district heating grids per connected home equivalent have been calculated for each district on the basis of the results of the *Startanalyse*. A cost curve has been plotted for the average district heating grid system costs in euros/home equivalent, depending on the heat demand density (building density) in those districts (see Annex). As explained under the potential market developments for district heating grids, building density has been divided into three different classes. Based on the cost curve, lower investment costs per connection are applied to districts with a higher building density.

The same district heating grid system costs have been calculated for LT grids as for MT grids, the only difference being the absence of auxiliary boilers in LT grids. The interviews do in fact suggest that, if the right principles are in place, LT grids ought not to cost more than MT grids. There is no central heat pump for space heating (see the Annex). In the case of the LT grid, an individual instant water heater for domestic hot water heating has been included in the investment costs for each home. More background on the cost assumptions can be found in the Annex.

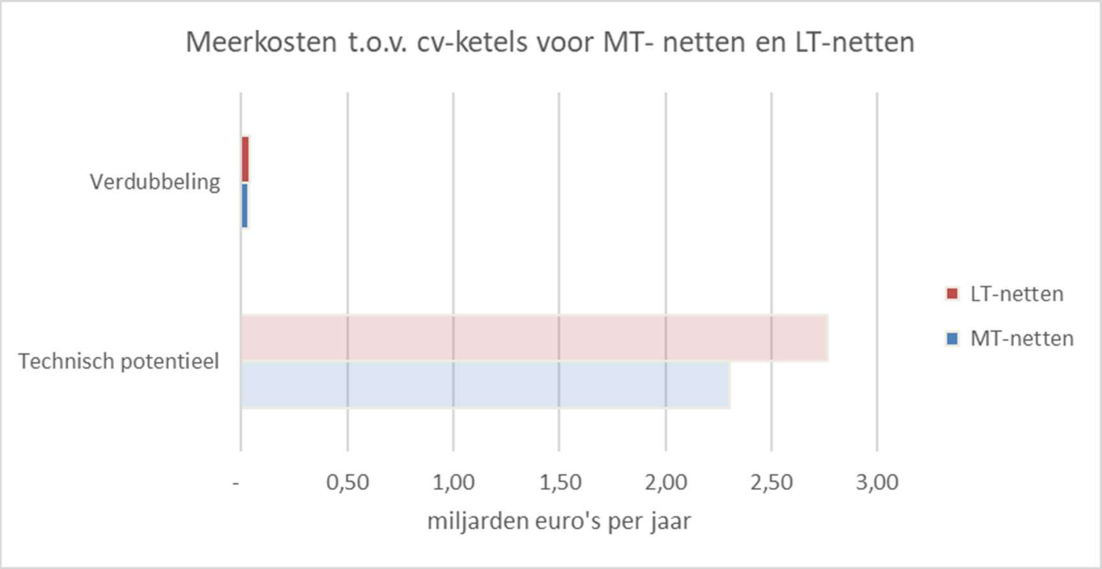


Figure I 3 Additional costs when compared to CH boilers (billions of euros per year) for MT grids and LT grids in 2030.

The result based on the assumptions translates into higher annual additional costs for LT grids when compared to MT grids. The additional costs for LT grids are 20 per cent higher than for MT grids. This difference can be attributed to the higher annual investment costs per home on account of the domestic hot water unit, which gives rise to around EUR 1000/home in additional investment costs for LT grids when compared to MT grids. This translates into 17 per cent higher annual investment costs. The operating costs of the distribution grid per year have been calculated as a percentage of the investment costs per year. These change in proportion and are 17 per cent higher as well. The energy costs for LT grids are 2 per cent higher, as the domestic hot water is produced using the electrical unit, but this does happen efficiently (the energy costs per GJ of heat are higher for electricity than for gas with the same efficiency). In the case of MT grids, all heat comes from the heat sources. A breakdown of the national costs is provided in the Appendix.

Summary

LT grids offer numerous benefits over MT and HT grids on account of better energy efficiency, improved exploitation of renewable LT sources, higher stability thanks to use of multiple sources, improved heat storage solutions and the possibility of cooling. They can therefore contribute to additional CO_2 emissions reduction when compared to MT grids. The calculations suggest that, if all homes, where possible, were to be connected to an LT grid, an additional annual saving of 2 Mt of CO_2 would be possible when compared to an MT grid.

The interviews do in fact suggest that, if the right principles are in place, LT grids ought not to cost more to install than MT grids. Heat storage could, for example, reduce peak demand, which could reduce the sizing of the pipes (see the ‘Heat storage’ sub-report). In addition, a large proportion of homes are already LT-ready, which means that no additional costs need to be incurred in the home, except for the domestic hot water supply. It is also important to include cooling demand in the business case, as cooling will play an important role in the future.

To overcome the lack of confidence in the comfort derived from LT heat, experiences of successful projects can be better shared with the industry as a whole. When it comes to upscaling, it is important that local authorities assume a leadership role, whereby they take an integrated view and have a future vision of heat and cold supply. They may be supported by a tool that can calculate local heat strategies and reliable approaches to reach decision-making.

J. Sub-report – large-scale heat storage

Introduction

Context

Heat storage has the potential to contribute considerably to the energy transition. By storing energy (in the form of heat or electricity) as heat for later use during times of surplus, sustainable sources can be more effectively utilised, congestion in the electricity grid can be prevented and additional (fossil) plants to cover peak demand can be avoided.

It is possible to distinguish between several different heat storage technologies:

- Sensible heat (Thermal Energy Storage (TES)) in water (usually temperatures between 0 and 100°C)
- Sensible heat storage in liquid salt, oil, sand, stone, ceramics (usually temperatures between 100 and 1000°C)
- Latent heat storage in phase-changing materials (PCMs)
- Heat storage in thermochemical materials (TCMs)
- Heat storage by redox principles

Sensible heat storage in water in particular is currently used on a large scale (larger than building level), such as in shallow/deep aquifers, mines, wells and water tanks. TKI UE has defined the trend: ‘Large-scale (heat) storage is difficult to implement’. In the MMIP, TKI UE outlines the following points for attention when it comes to upscaling heat storage:

- Reducing purchasing and installation costs and operation
- Improving (system) efficiency
- Further improving, demonstrating and integrating large-scale heat storage systems into collective heat systems
- Reducing the use of space and improving the appearance of above-ground and underground components
- Further developing new, large-scale heat storage methods
- Further developing concepts to bridge longer distances between heat supply and heat demand

Reading guide

The qualitative section of this sub-report comprises the ‘Developments in the technology’ and ‘Boundary conditions for upscaling’ ‘sections and is based on desk research and the interviews with Marette Zwamborn (KWR Water) for large-scale storage in an underground aquifer (particularly soil energy and high-temperature storage) and with Ruud van den Bosch (GroeneWarmte) for large-scale storage in tanks and ‘pits’. The qualitative section is a selection of the key bottlenecks, developments and boundary conditions for upscaling according to those interviewed.

The quantitative section, comprising the ‘Potential market developments’ and ‘Impact’ sections, was put together by TNO. The assumptions used here were agreed with TKI UE and are based as much as possible on the interviews and the KEV (PBL, 2021). As explained in the introduction, we wish to emphasise the fact that we do not make predictions on the achievement of the presented potentials. The potential market developments do, however, show that there is greater potential, which according to the KEV is not yet being utilised.

The sub-report concludes with a summary of the insights from both sections.

Developments in the technology

Summary of interview with Marette Zwamborn on STES and HTO (KWR Water) and with Ruud van den Bosch on tanks and pits (GroeneWarmte)

General

The interviews relating to large-scale storage have focused on low-temperature and high-temperature aquifer thermal energy storage and storage in a tank (tank thermal energy storage) or pit (pit thermal energy storage).

In the case of Aquifer Thermal Energy Storage (ATES), sensible heat is stored in an underground aquifer. It is a mixture of generation and storage (maximum 25 degrees charge temperature in the case of open systems (=STES) and 30 degrees in the case of closed systems) and has the benefit that it can also provide cold, which is often neglected. The Netherlands is a world leader in the use of ATES on account of suitable soil conditions and a favourable climate for seasonal storage. It is ideally suited to lower temperature demand, such as in newly built homes, as well as in buildings with demand for cold. ATES has come about since 2000, and its growth has largely paralleled the construction of new buildings (see also bodemenergie.nl).

High-temperature storage (HT-ATES) is heat storage from around 50 degrees. A number of pilots are now underway to target depths of at least 150 metres. Storage is intended to mirror the scale of a district. HT-storage has a number of benefits when compared to a STES, as the storage has a higher energy density and can prevent grid congestion, as no heat pump is needed to supply the heat. HT-storage is still in the development phase for studies into aspects such as:

- Knowledge of the subsurface, specifically at the depths of high-temperature storage
- Spatial policy and a policy framework for high-temperature storage, based on knowledge of the boundary conditions under which high-temperature storage can be used sustainably in the soil
- Technological developments with research questions such as:
    - How do you connect to the system?
    - At what times do you utilise the heat?
    - What materials do you use?
    - How much heat can you feed back from storage?
    - What happens to the heat underground?
- Insight into the business case for high-temperature storage

Another means of storing sensible heat is to store water in a tank (TTES) or pit (PTES), which requires a storage system to be built. This means that there are high investment costs and that there needs to be space for the tank or pit, but the benefit is the lower heat loss of 10 to 20 per cent when compared to the 30 to 40 per cent for an ATES system (CE Delft, 2020). This form of storage is not yet used on a wide scale in the Netherlands. Due to high groundwater levels, pit storage is also not always possible in the Netherlands.[23] Some technological developments for tank and pit storage are:

---

[23] Studies are underway to determine whether large pits are possible with high groundwater levels.

- Development of hydraulic and thermodynamic simulations to be able to determine how the heat system will work –this is somewhat complex as a result of things like stratification and turbulence. These simulations can be used to help improve the design.
- A new ‘liner’ technology, particularly for pit storage, with a longer service life and improved resistance to higher temperatures or to certain components in the water
- When it comes to floating covers, research is being undertaken into how to make these better or cheaper, such as a round floating cover instead of a square cover.
- Research into polymer concrete, which has a lower CO_2 footprint and is more resistant to certain substances and decalcified water (heat exchangers have low resistance to lime, while decalcified water draws lime from the concrete into the wall of the storage).
- Experiments with floating covers in surface water, such as gravel pits, and partially submerged steel tanks

Reducing purchasing and installation costs and operation

Installation of ATES systems requires a relatively high investment. It is not expected that CAPEX costs can be reduced much further due to the unavoidable costs incurred when working in the soil and the fact that this work must be carried out with great care. There is the possibility of cost reduction in the long term on account of the learning curve that comes about through more frequent use. When it comes to high-temperature storage, there are still many areas of uncertainty relating to the costs and benefits that must be resolved before a picture of the business case can be built up.

Tank and pit storage require higher investment costs than an ATES. Investment costs for pit storage still have the potential for reduction because of the learning curve and upscaling. In the Netherlands, pit storage now costs around EUR 70/m^3. In Denmark, the figure is EUR 30/m^3 – perhaps we can reach this figure in the Netherlands as well. When it comes to tank storage, Ecovat now costs EUR 160/m^3 for the largest storage capacity. If capacity increases further, a different construction method should be considered. The concrete wall of the Ecovat principle may well last for a century, but that generally has very little monetary value in the business case.

A high CAPEX does not necessarily mean there is no business case for it. The business case for heat storage is simply extremely complex, also because it is layered. For example, heat storage not only has benefits for the heat company, but with power-to-heat, can also make more efficient use of overproduction of electricity and avoid grid congestion (and thus the costs for grid reinforcement). These benefits do not have any current value, however. In addition, energy prices (and their volatility) are also important factors that make the business case for a storage system built to last for 30 to 40 years more challenging. Uncertainty about energy prices also makes seeking finance from a bank difficult.

The experts interviewed do not anticipate a significant reduction in the CAPEX costs for an ATES or tank storage in the short term; there remain opportunities for pit storage through economies of scale.

Process

The design of an ATES system differs between locations. The underground is very location specific and requires prior investigation each time, such as into contamination and the effect on surrounding systems. In addition, management of the underground is fragmented. Policies and permit conditions may also differ between provinces or local authorities. Local authorities have very little capacity and knowledge in this area.

When it comes to high-temperature storage, there is no generic policy framework, and permits have only been issued for pilot projects.

There is little experience with heat storage in tanks and pits, which means that heat companies and local authorities still have many questions and uncertainties. Initiatives and decision-making in this regard are thus tricky, and processes are lengthy.

Both the installation of an ATES system and storage in tanks and pits are lengthy processes. In the case of an ATES system, this is mainly due to (the need to deal with) differences in the underground at the location, local rules and local permit conditions. In the case of tanks and pits, parties still have many questions due to unfamiliarity with the storage system.

Boundary conditions for upscaling

To be able to upscale STES, it would help if policy rules and permit conditions were more consistent. A lot of time is currently spent researching local policy and local responsibilities. The collective interest (better utilisation of sustainable resources) and the benefit of buffering (efficiency and costs) are not always clear amongst parties. To be able to further develop high-temperature storage, pilot and demonstration projects need to be carried out to investigate the technical, financial and legal aspects and eliminate the bottlenecks.

For tanks and pits, a standard assessment framework could help to support heat companies and local authorities with the decision-making process. Simulation models and performance certifications of heat storage systems (such as energy efficiency and service life) can also help heat companies with the design and provide clarity on what to expect from the system and how to benefit from it. In addition, pilots can contribute to new insights, practical experiences and the elimination of uncertainties. A subsidy scheme for heat storage would also highlight the value for the energy transition and encourage its use.

Finally, there is little incentive to store heat via power-to-heat at times of overproduction. For example, the sustainable use of electricity for heat storage is not valued. (Heat) companies do maintain a sustainability target, but for heat storage, no distinction is drawn between sources of electricity in the use of power-to-heat. Whether or not regular electricity is used or whether electricity from wind farms and solar farms is used during overproduction makes no difference – each kWh has the same sustainability rating, and heat companies receive a single sustainability certificate for the year as a whole. In addition, the sustainability of the district heating grid does not count in the BENG standard for newly built homes; instead, a standard value for the sustainability of a district heating grid is used.

Potential market developments

For the potential heat storage market developments, we calculate the impact of large-scale heat storage in an underground aquifer (soil energy or aquifer thermal energy storage

(ATES)) and storage in a tank (tank storage). The point of departure for heat storage is the number of homes that are connected to an LT district heating grid by 2030, through which these potentials are linked to those of ‘District heating grids’. The number of homes in which collective heat storage is used is shown in Figure J 1. In this sub-topic, we look at the difference in impact between a low-temperature district heating grid with and without heat storage. The following table provides an outline of the potential market developments and the boundary conditions associated with those developments.

Baseline

For the Baseline, the starting assumption was the number of homes assumed to be connected to a district heating grid in 2030 in the KEV 2021 under the adopted and intended policies. In 2020, 426,000 homes were connected to a district heating grid (at all temperature levels); in the KEV estimate, this rises to 694,000 homes by 2030, an additional 269,000 in 10 years. This figure also includes newly built homes that are to be connected to a district heating grid. For existing buildings, this means an increase of 84,000 homes between 2020 and 2030. This is insufficient to meet the target in the Climate Agreement – a growth of 750,000 new connections in existing buildings by 2030.

Doubling

In this potential development, we assume a doubling of the increase in the Baseline (the KEV) for existing buildings. With a doubling, or an additional 84,000 homes connected to a district heating grid, the total connected existing homes would be 510,000 by 2030.

Technical potential

For the assumption relating to the technical potential, we assume that 100 per cent of existing homes located within an area classed as having a building density of high or medium will be connected to the district heating grid by 2030. That is more than 6,000,000 homes. As stated above, this is in no way intended as a realistic scenario, but as an indication of the theoretical range.

Table J 1 Description of potential market developments for large-scale heat storage

Potential market developments for heat storage	
	Description
Doubling	Doubling when compared to the Baseline of the number of existing homes connected to a district heating grid by 2030
Technical potential	All homes in this market development in the case of ‘District heating grids’ that are connected to an LT grid have heat storage
	Boundary conditions
Doubling/ Technical potential	- The benefits are recognised and valued, creating a favourable business case - There is consistency in policy rules and permit conditions, and there are standard assessment frameworks

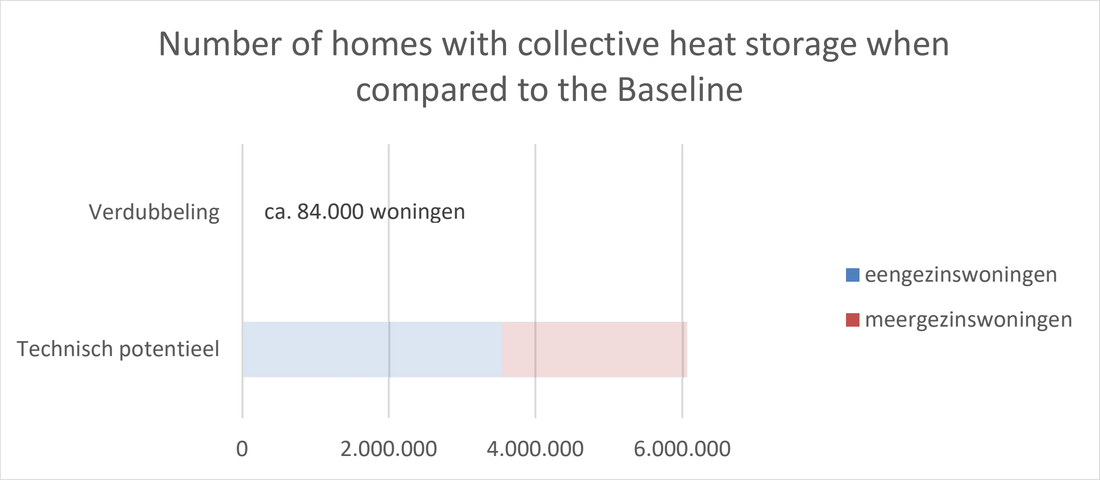


Figure J 1 The number of additional homes in 2030 when compared to the Baseline with a collective heat storage system by potential market development and with a distinction between single and multi-family homes.

Requisite innovations

According to the experts interviewed, the upscaling of soil energy or tank storage does not require any fundamental innovations, but it does require consistency in rules, permit conditions and assessment frameworks. In addition, the benefits are not yet always valued or do not yet reach the party that incurs the costs, so there is no favourable business case. Innovative storage technologies, such as high-temperature storage (HTO), thermochemical materials (TCMs) and phase-changing materials (PCMs), can also offer new solutions for more efficient and more compact heat storage that is more cost effective in the long term. PCMs are beginning to come onto the market, but high-temperature storage and TCMs are still in the development phase and require grants or investments for further development.

Impact

This section calculates the potential impact of a sub-topic for different market developments by comparing an LT grid with and without heat storage. This section focuses solely on a quantitative impact calculation of CO_2 emissions reduction and national costs. Other impacts of a higher market share or an innovation, such as more potential for flexibility with the electricity grid, are not taken into consideration.

CO_2 emissions

Heat storage can bring about savings in the use of natural gas, as renewable sources can be better utilised and auxiliary boilers need to be used less frequently to cover peak demand. In the calculation, we have made an assumption about the percentage of heat storage, which has not been tested against practice. We base our assumptions on the fact that, in district heating grids, the typical distribution of heat production between primary heat source and auxiliary boilers on an annual basis is around 80 per cent to 20 per cent (PBL, 2021). We assume that some or all of the heat still supplied by auxiliary boilers on natural gas can be replaced by heat from storage. In addition, seasonal storage of heat can also be used, which ensures more utilisation of renewable heat. In De Groot, 2021, the comparison of different heat storage technologies assumes that 25 per cent of total heat demand comes from storage on an annual basis. That percentage has been used here as a point of departure for the additional utilisation of renewable heat storage in both an aquifer and tank storage.

On account of this assumption, the reduction in CO_2 emissions achieved is the same for these storage technologies. The CO_2 emissions reduction achieved is shown in Figure J 2. If the LT grids in the 'Doubling' market potential were to use heat storage, this would lead to an additional annual reduction in CO_2 emissions of 0.01 Mt when compared to the situation without heat storage. If the LT district heating grids in the technical potential were also to use heat storage with the aforementioned assumptions, the additional range of CO_2 emissions reduction would be around 2.7 Mt.

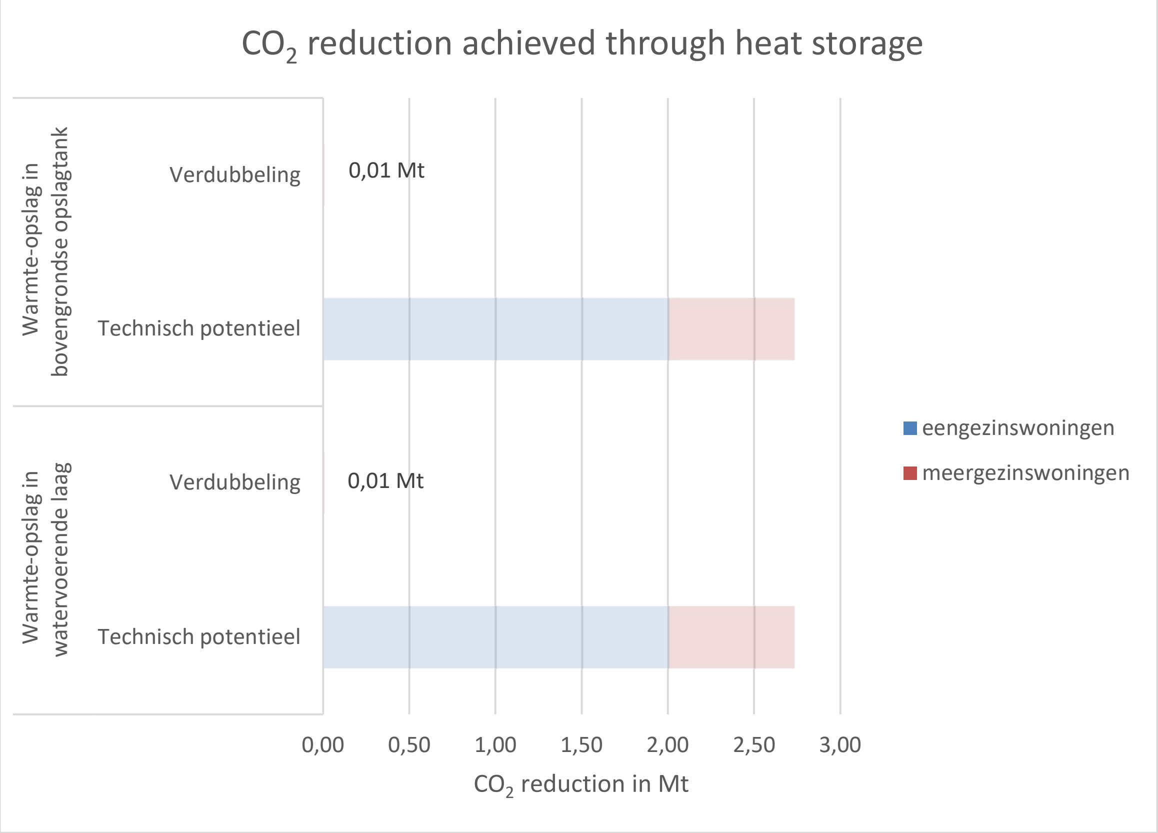


Figure J 2 CO_2 emissions reduction for heat storage by 2030 for two storage technologies with a distinction between single and multi-family homes.

National costs

A study into heat storage in the Netherlands (De Groot, 2020) undertook a technical-economic comparison of different large-scale energy storage technologies for heat in homes. We have used the information from this source to calculate the national costs. The study shows that tank storage involves higher specific investment (euros per m^3 of storage) by a factor of ten than underground storage in an aquifer.

To determine the storage volume required per single-family home and multi-family home, an efficiency for heat storage of 75 percent has been assumed for aquifer storage and of 90 per cent for tank storage. These are averages for efficiency taken from a study into heat storage carried out by CE Delft (Schepers & Dehens, 2020). The determination of how much storage volume is needed per home is explained in greater detail in Annex C.

The investment costs for each home equivalent have been calculated using the storage volume in m^3 per home required to store the share of heat demand on an annual basis. In addition, 0.75 per cent of the investment costs per year has been taken as maintenance costs for tank storage above ground on the basis of (De Groot, 2020), and using the same study, no maintenance costs have been calculated for storage in an aquifer. The fact that there are no maintenance costs applies to the aquifer itself, but not to the water pumps that need to be replaced every few years. Pump energy for pumping and circulating heat from storage, and the investment costs for the pumps, have not been taken into consideration as part of the comparison (no data were found to provide a good basis for this). In the case of an aquifer, significant more pump energy is needed than for tank storage, as in the latter case, motion energy from free-fall is utilised. The grid reinforcement costs that may be avoided due to heat storage are not taken into consideration in these calculations.

The result (see Figure J 3) shows that the investment of storage in an aquifer is limited to such an extent that the savings in energy costs for natural gas (on account of the additional renewable heat utilisation) give rise to negative national costs (savings). This makes it an appealing solution from a national costs perspective. By contrast, investments for tank storage are many times higher and involve significant national costs of EUR 0.85 billion per year.

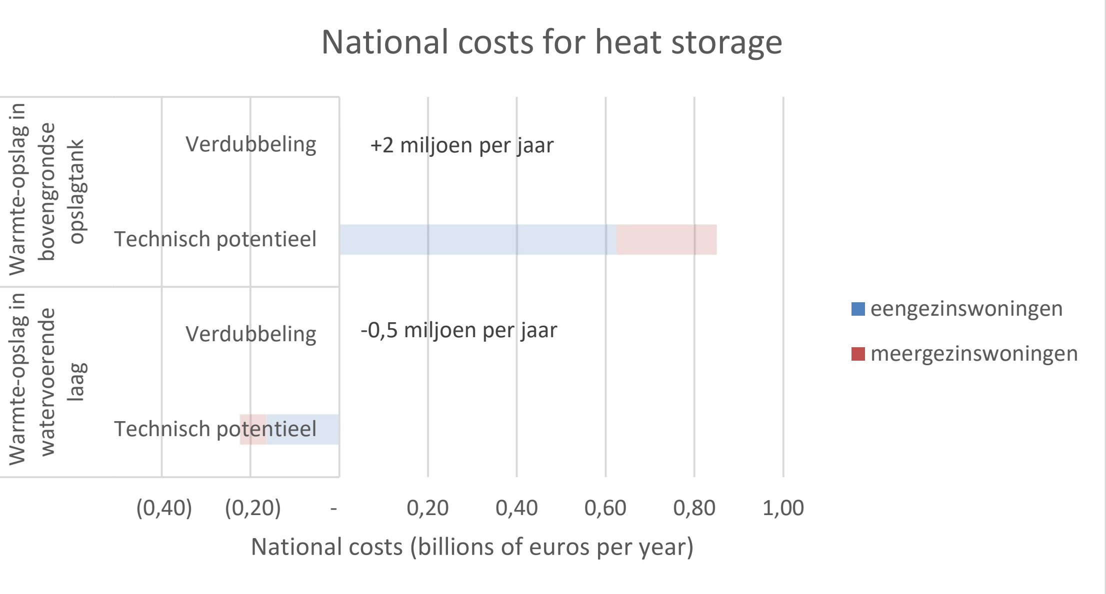


Figure J 3 National costs for heat storage by 2030 for two storage technologies with a distinction between single-family homes and multi-family homes

Summary

Heat storage can contribute to the energy transition by making better use of renewable energy sources, thereby avoiding the use of natural gas in auxiliary boilers at times of peak demand; flexibility with the electricity grid can also be realised. These benefits of heat storage are not yet always recognised and appreciated, however, which means that the costs and benefits do not always rest with the same party and there is no business case.

The impact calculations, based on the assumptions in this study, give a cost saving for water storage in an aquifer (soil energy) due to the savings in gas use. Storage in a tank is ten times more expensive and gives rise, therefore, to additional annual costs. In the case of a doubling (when compared to the KEV) of the number of homes that are connected to an LT district heating grid, 0.1 Mt of CO_2 emissions can be avoided on an annual basis when compared to a district heating grid without heat storage.

According to the experts interviewed, in addition to a greater incentive to store heat, consistency in policy rules and permit conditions as well as standard testing frameworks are boundary conditions for upscaling.

K. Sub-report – energy collectives

Introduction

Context

Energy collectives have long played a role in energy markets. According to the Local Energy Monitor of ‘HIER opgewekt’, the Netherlands had more than 650 energy collectives in 2021, with an estimated number of members of around 110,000. The number of energy collectives continues to increase, and growth in current collectives in membership terms continues.[24] The overwhelming majority of collectives work on solar energy projects. In addition, there are also collectives that invest in wind and an increasing number of collectives that focus on heat and the development of district heating grids. Another activity that many collectives have chosen to focus on is energy saving.

Many different names are used for energy collectives, including microgrid, community Virtual Power Plant (cVPP), peer-to-peer energy community and energy hub. The name is often derived from an activity that the collective is developing, or a geographical feature of the collective. These archetypes have no legal meaning and are hard to delineate – they simply indicate what is ‘typical’ for energy collectives of this kind.

TKI UE describes the development of energy collectives as follows: *‘The collective and local organisation of energy supply and demand control from bottom-up initiatives is increasingly becoming a component of innovation projects.’* The trend description is consistent with the development of collectives and the need for more innovation and more ‘independent’ operation in, for example, energy markets.

European legislators have hopes that energy collectives can contribute to the increase and integration of sustainable sources and thereby help to empower energy consumers. The community must be treated with fairness and be able to operate on an equal level playing field. European legislators are thus keen to empower consumers to make a more active contribution to the energy system. They ought to be able to participate, whether directly or indirectly, in the market by generating, storing and trading sustainable energy, thereby benefiting from lower prices.[25] They can do this on an individual basis, as active customers, or as a group of active customers in the form of an energy community.[26] The latter is an inclusive solution, giving all consumers the option to participate in joint production, consumption and sharing of energy.

The introduction of the new European legislative package known as ‘The Clean Energy Package (CEP)’, a package of European directives and regulations, legally codifies the energy collective. The Electricity Directive and the Renewable Energy Directive contain two definitions of *energy communities:* the *energy community of citizens* and the *renewable energy community*. The definitions make a statement about the way in which communities should be organised, the purpose for which they have been established and the activities that they should be able to develop (Florence School of Regulation, 2021). Both definitions

---

[24] The Local Energy Monitor 2021, HIER opgewekt

[25] Directive 2019/944, considerations 37, 42

[26] Directive 2019/944, considerations 43 and 44

include a non-exhaustive list of activities.[27] The following explains the core elements in the definitions in further detail.

What is an energy community?

European legislation states that energy communities are distinct from other market parties in that they serve a different purpose. In the first instance, the purpose of the community is to provide environmental, economic or social community benefits to its members or shareholders. The pursuit of profit is not the primary driver (although this does not mean that communities ought not to make a profit).

In addition to the purposes pursued by the community, organisational and control requirements are also characteristic of the energy community. Control within the community rests with the members or shareholders, and specifically with members who are natural persons, local authorities or small enterprises. The community is a legal entity, and membership is open and voluntary. Shareholders and members have the right to leave the community. The definition makes a statement about who is permitted to join the energy community – primarily domestic customers.[28] The participation and authority that members/shareholders enjoy in the community is also an important feature by which the community can distinguish itself from other market parties, such as a 'regular' energy supplier.

Finally, the definitions make a statement about the activities that energy communities are able to develop. As an example, the directives state that energy communities should be able to produce, store, consume, aggregate and share. The activities an energy community undertakes are not what distinguish an energy community from another market party, but rather *the way in which* they are *organised*, *who has control* and *the purpose behind the activity*.

Reading guide

This sub-report only has a qualitative section, which comprises the 'Developments' and 'Boundary conditions for upscaling' sections. The sub-report concludes with a summary of the insights.

Developments

The energy community or energy collective is thus a group of affiliates (primarily domestic customers) who develop activities together. Energy collectives are becoming increasingly professional, which translates into the types of activity that collectives are keen to develop. An ever-increasing number of collectives are focusing on innovation. As an example, energy collectives exist that not only produce sustainable energy, but jointly invest in batteries and store energy together, car shares and smart charging infrastructure. Energy collectives are also experimenting with activities that could contribute to relieving the strain on the grid, and there are also collectives that are interested in supplying to their members and wish to become an energy supplier.

---

[27] In practice, there are many different types of energy collective. Not all energy collectives fall under these two definitions.

[28] As well as local governments and small enterprises. The description of the energy community of citizens also permits other entities to join the community, but it does stipulate that decision-making authority within the community should not rest with parties that undertake large-scale commercial activities. Consideration 44 to Directive 2019/944

The need to be more active in energy markets is also translating into new European legislation, in the form of the Clean Energy Package (CEP). Some of the activities in the CEP must be facilitated by Member States, while other activities, such as *operating distribution grids*, may be facilitated by Member States. The summary of what the energy community ought to be able to do is an instruction to Member States to make this possible. The definitions in the Electricity Directive and the Renewable Energy Directive are now also being implemented in the new (draft) Energy Act.[29]

Including an official definition in the Energy Act only is not sufficient for upscaling the energy community. In the first instance, it is the recognition of a desired development. European legislators are keen for households, small businesses and governments to jointly engage in activities that deliver environmental, economic or social community benefits. To then facilitate this as well, it must be examined how the realisation of energy communities can best be supported and, for each activity that communities wish to develop, whether they can develop them and under what conditions.

Boundary conditions for upscaling

When it comes to upscaling energy communities as a new player in the market, work is needed on several bottlenecks and boundary conditions. Just like any other market party, it must be ensured that the activity the energy community wishes to undertake is technically, legally and financially possible. The boundary conditions required for the upscaling of energy communities as a new actor in the energy market are thus chiefly related to the activities that they wish to develop.

The following are some points for attention relating to the upscaling of energy communities. The list is not exhaustive, but the result of an initial exploration based on desk research and interviews.

Framework and support

In the first instance, there needs to be a clear picture of where energy communities can contribute: how should energy communities play a role in the empowerment of energy consumers, and what role should they play in the energy market? There will then be a need to look at **what activities** match this role and under what conditions they can be developed.

An important boundary condition for the upscaling of energy communities is a **clear legal framework**. Among other things, this means ensuring that the activities that energy communities ought to be able to develop, such as supply, generation and aggregation, are adequately supported. There should also be an examination of whether there are any disproportionate barriers impeding these activities. These could be legal impediments, as well as **economic impediments.** The text box contains two pertinent examples.

---

[29] Draft proposal containing rules on energy markets and energy systems (Energy Act), July 2022, Council of State Version

Two examples of legal and economic support
Suppose that an energy community 1) wishes to supply self-generated electricity to its members and 2) wishes to steer towards as much local and sustainable consumption as possible.

1) To be able to supply households, the energy community currently requires a supplier permit. The permit imposes requirements on the supplier to protect the end customer. These requirements can be disproportionately inhibiting for smaller parties, such as energy communities. Legislators in the Netherlands have thus opted to include an exemption in the new Energy Act, relieving energy communities (and active customers) of the need to obtain a permit.

2) The energy community wishes to consume as much energy as possible locally and sustainably. This activity could be encouraged through a tariff incentive, such as a lower transmission tariff if the energy generated is used nearby. By offering a discount on transmission costs, community members can be encouraged to consume as much locally generated energy as possible.

Data exchange plays a key role in the undertaking of activities. It is important that data can be accessed and shared both securely and reliably. Energy communities could be supported in this.

Technical innovations can also contribute to facilitating and simplifying certain activities – activities such as bringing supply and demand together locally require new methods of communication and data sharing. Blockchain technology or a distributed ledger, for example, could be used to establish a trading platform for the community (Andoni, et al., 2019). Making innovations like these available can allow communities to obtain greater insight into their own energy flows and flexibility options. It can also support communities with the legal tasks that are a part of undertaking an activity, such as sending bills and preparing accurate forecasts of their consumption and generation profile.

The development phase

The energy community is not only a player in an energy market but is first and foremost a collaboration between citizens and other local actors. Collectives are often established from the bottom up. Establishing an energy community is a challenge and requires considerable knowledge, time and resources. It also requires the right combination of knowledge, skills and collaborations within the local network. As such, there is a need for **good examples** of collectives that provide insight into **the organisation and governance** structure of other initiatives and into the agreements made between the community and other market parties. Homeowners also need to have the knowledge and tools to develop a **value proposition,** and approaches on how to involve the surroundings in a new initiative are also essential.

Finally, a significant bottleneck is the **financing** of an initiative. The **scale** and **creditworthiness** of individual initiatives are two of the main obstacles to gaining access to finance. Research into how initiatives can be bundled to create scale is necessary. In addition, work is needed to improve the creditworthiness of initiatives – one such approach could be to create scale or arrange for financing to be handled by an umbrella organisation or other local organisation. Social housing associations could also play a role in this. Moreover, communities must also be accessible to low-income households. An exploration of the public and private financing instruments that could play a role in this is needed.

Summary

In the Netherlands, there is already ample experience with energy collectives and sustainable energy generation. Over the past few years, an ever-increasing number of collectives has been looking at developing new activities, such as storing and trading energy. There is still only limited experience in these areas. European and Dutch legislators are encouraging this development and would like energy communities to be able to participate in energy markets as equal players, so that they have the ability to contribute to the increase and integration of sustainable sources and to the empowerment of energy consumers.

The energy community is now a firm part of the new draft Energy Act. Subsequently, there is a need to look at the role that communities ought to play in the market and the conditions under which they should be able to develop activities. To be able to upscale energy communities, it is important to look at the technical, legal and economic bottlenecks that need to be resolved for each activity in order to create favourable boundary conditions for upscaling.

The start-up phase of initiatives also brings challenges, particularly when it comes to involving homeowners and providing sufficient knowledge and skill. In addition, access to finance is also a bottleneck, and new funding instruments need to be examined. It is important to look at options for upscaling and for improving the creditworthiness of collectives.

L. Sub-report – human capital and labour productivity

Introduction

Context

The labour market for sustainability in the built environment is currently experiencing a shortage of technicians and other personnel needed to accomplish it.[30] TKI UE has observed the following trend:

‘Construction, installation and maintenance industries commit to increasing labour productivity and making tasks suitable for lateral entrants.’

This sub-report analyses the impact of two innovations on the supply of and demand for labour and describes labour market dynamics in the construction sector. Consequently, this topic has a different format to other sub-reports.

Reading guide

This sub-report has only a qualitative section, which comprises the ‘Developments’ and ‘Boundary conditions’ sections. ‘Developments’ considers two innovation case studies on the basis of two expert interviews: 1) Integrated (prefabricated) installation of heat pump, ventilation and domestic hot water systems with Wilfried Jonker (Factory Zero) and 2) Industrialisation of façade and roof renovation for existing buildings with Berri de Jonge (Plegt-Vos). This considers the innovation itself, the impact on use of personnel and the bottlenecks for further development. In ‘Boundary conditions’, we look at how supply and demand in the labour market for sustainability relate to one another and what dynamics could occur if the two are out of balance. The sub-report concludes with a summary of the insights.

Developments

Innovation case study – Factory Zero

Factory Zero produces an integrated Climate Energy Module (iCEM) that can supply a home with ventilation, space heating and domestic hot water (using an air-water heat pump). Solar PV or cooling can also be added as a solution. The construction process followed by Factory Zero has largely been moved from the construction site to a plant, where the module is assembled. It is then simply installed in the home. Factory Zero currently installs around 1000 iCEMs per year.

---

[30] PBL-ROA (2022) Insight into labour market bottlenecks for the implementation of climate policy; UWV (2022) Climate jobs in the built environment; EIB (2022) Construction capacity analysis memo; SER (2018) Energy transition and employment; Techniek Nederland (2022) Economic forecasts for 2023 and beyond; FME (2020) Technology for a future-proof built environment.

The impact of innovation

The purpose of the adjustments in this process is to lower the use of specialist installers for installation. By shifting production to the plant, personnel without specialist training and certification can carry out many of the tasks involved. Specialists can then handle specialist tasks on the shop floor, such as adding F-gases and adjusting the appliance. These specialists no longer need to travel to the construction site. The iCEM modules are plug and play, which means that, at the construction site, installers can complete the work within a few hours (a half day). This task specialisation has reduced the total labour use per module from 40 hours to just 8 hours and the use of specialist installers from 10 to 4.

This has also increased the labour potential by keeping specialist installers in employment, even at an older age. This gives these installers around a decade more of employability before they retire. In addition, tasks can now be carried out by personnel who have been recruited from outside the industry – people who would not be interested in working on a construction site, but who are interested in work in a plant. This work is also more easily accessible to people with poor job prospects.

Potential and further development

Based on the figures above, we can perform a simple calculation of the potential of this way of working. Assuming the Government’s target of 100,000 newly built homes per year, plus the approximately 450,000 central heating systems that are replaced each year, the total market for this type of system is 550,000 per year. Of this amount, Factory Zero estimates that 80 per cent may be eligible for standardisation and the industrial production method. In 20 per cent of cases, customisation will be necessary due to the complex nature of the situation.

The remaining potential is then 440,000 systems per year. Assuming that the same saving can be achieved as at Factory Zero, this would mean a saving of 13.2 million labour hours, of which 2.64 million would be specialist labour hours. With a standard 40-hour working week, this works out to around 80,000 and 16,000 working years respectively. At the same time, the potential workforce can also be expanded by drawing people from outside the construction industry to work in the plant. The latter is still difficult to quantify.

Factory Zero sees further development of the concept, particularly when it comes to integration with other building components that are needed for sustainability. Factory Zero views a combination with façade renovation on homes and components that are more modular in nature as promising directions. Further optimisation of the production process with robotisation, for example, will only become commonplace once there are economies of scale.

Innovation case study – Plegt-Vos

In June 2022, Plegt-Vos opened a Smart House Plant in Almelo, a move that was triggered by the construction crisis of 2008 to 2013. The decline in personnel was difficult to recover from, and Plegt-Vos noticed that it needed to do more with fewer people to do it. With this in mind, it has switched part of its production (now roughly 40 per cent) to a different production method by means of far-reaching standardisation and automation to enable more prefabricated construction.

This means standardisation of processes at multiple locations and bringing uniformity to the input and output. This also helps to increase the interchangeability of personnel between locations, allowing work planners to distribute capacity between offices and allow offices to take over tasks from one another as needed.

The impact of innovation

Plegt-Vos is still in the middle of the transformation process. Consequently, concrete figures on the expected gains in labour productivity actually achieved are not yet available. Not all of the potential that this way of working brings has yet been accomplished. What can be said, however, is that automation and robotisation have great potential. Masonry and nailing robots, for example, can assume the jobs of more than one hundred workers. Even now, more work can be completed with fewer skilled workers in the plant.

Standardising and interchanging personnel between locations improves personal employability and, most likely, productivity as well. In addition, it also ensures that innovations and improvements in processes can be shared more quickly between locations.

Plant employees are also covered by the carpentry CLA, which makes Plegt-Vos more attractive to personnel than other plant jobs in the labour market, while also tying them in to relatively high salaries. At the moment, this helps with attracting personnel from outside, who would not normally be on the lookout for this kind of work.

An important advantage that Plegt-Vos can already see is increased job satisfaction. Construction site personnel are happy that products coming from the plant fit properly and that less time is lost on site trying to devise solutions. Plant personnel need to do less physical work and can carry out more varied work. Skilled workers who enjoy working on bespoke projects can thus specialise in these kinds of job. In this regard, the plant can attract more personnel who enjoy process improvements, and fewer who are problem-solving thinkers.

Potential and further development

The potential of this production method has not yet been fully realised. It is already easy to employ in new building projects but is not yet fully in line with demand in the renovation market. While it is no longer necessary for plant staff to be able to read an architectural drawing, Plegt-Vos experiences a bottleneck in the engineering of its products for renovation. The number of designers needed to fill plant capacity is not currently available.

The use of standardised products for renovation is highly dependent on proper incorporation of the works. Although contingents can be used when it comes to determining the size of the market overall, checking the specific situation is still essential to ensure that the products fit that Plegt-Vos can produce in a standardised process.

Clustering the demand of similar homes could be a major step in further unlocking the potential of industrialisation for the renovation market. This would allow a large proportion of the engineering of products to be standardised, which would represent a step forwards in terms of efficiency. A different approach to tendering by corporations could also be a significant contributor.

Boundary conditions

The acceleration needed for sustainability for the built environment and government instruments focused on this mean that additional sustainability (on top of what would happen naturally) is needed. This gives rise to a tight labour market. This tightness is not evenly distributed, however, and will be more of an issue for some occupations than for others. The following outlines the impacts on demand for labour and supply separately, after which we consider the dynamics between the two.

Demand

The climate targets and government instruments focused on the built environment will increase production in the construction sector, thereby increasing demand for certain occupations. This can lead to shortages, both in a generic sense and for specific groups of occupations. The increase in demand as a result of government instruments is in addition to an assumed baseline. Without a target, there are no bottlenecks.

At the same time, demand for certain other occupations is decreasing. Standardisation of heat pumps, for example, could cause demand for heat pump installers to rise, while reducing demand for CH installers.

If the increase in demand cannot be met, the price for labour will increase. As a result, some of the demand could drop away again (causing the target to be missed).

Supply

The supply of labour can increase to match demand in roughly two ways – an increase in labour productivity or an increase in the number of people in occupational groups.

Firstly, labour productivity can increase. In other words, this refers to production per labour year. As an example, a temporary period of high work pressure following a period of relative calm could mean that professionals do more work. In addition, labour productivity can increase through task specialisation (i.e. transferring some of the tasks of specialists to auxiliary workers), allowing specialists to focus on the more complex tasks for which training or experience are required. As a result, the demand for specialists can be replaced by demand for auxiliary workers. This might cause a decrease in tightness for specific occupations and increase labour potential by attracting people from outside the industry.

Tasks can also be relocated within the chain. If more plug-and-play systems are developed, work may shift from the installation site to a plant. This would result in an overall increase in productivity and opportunities for task specialisation and automation. It would also open the door for groups in the labour market who cannot or do not want to work on construction sites. These groups could be installers who are looking for less physical work or new groups who have not previously worked in the industry. It can also reduce travel time for the highest-paid specialists, by shifting the bulk of their work to the plant. Furthermore, the same installer can install more systems, as they have to spend less time on each system on site.

Finally, if there is tightness in a particular group of occupations, pressure begins to emerge on salaries. In that case, companies may find it beneficial to invest in labour-saving technologies. This would increase labour productivity through automation or robotisation.

Secondly, the number of people in specifically tight occupational groups may increase. Every industry has a natural turnover of personnel. Intake of personnel takes place from training courses, lateral entry or abroad. Outflow of personnel takes place to retirement, lateral outflow or abroad. By increasing the intake or reducing the outflow, the supply of personnel in a certain occupational group will grow. Labour conditions can then improve to help retain people in the industry or attract more people. This could include salary, but also attractive working hours, challenging work, less physically demanding work, favourable fringe benefits, a good pension, etc.

It is important to point out that tightness does not just exist in the built environment – in theory, the number of skilled people is sufficient to accomplish the task in the built environment (with a short course for technology-specific knowledge). These people are also in high demand in other industries, however. Through the labour market, different industries are in competition for the same personnel. The industry in which the best working conditions are offered will attract the most people. The greater the difference between industries, the greater the incentive for personnel to retrain and change jobs.

Interaction between supply and demand

The interaction between supply and demand will take place through the price of labour (salary plus costs of fringe benefits). This will then determine the price of production. Predictions about shortages in specific industries are possible in the short term, but looking farther ahead, there is likely to be a complex dynamic between supply and demand that is difficult to predict. A balance between the demand for and supply of labour will translate into a price for labour that is consistent with trends in the economy as a whole. The rate at which this balance is achieved differs by specialism and the general state of the industry.

The anticipated recession could be a catalyst for a shift in the labour market towards high-demand occupations. We should expect that the least productive jobs, which remained in existence during the coronavirus pandemic due to support measures and low interest rates, will move aside to let in jobs in industries where there is a major shortage.

Summary

The climate challenge in the built environment is currently experiencing labour market bottlenecks. In the medium term, market forces may cause these bottlenecks to resolve themselves, but they could put the brakes on the energy transition just when acceleration is needed. To be able to meet demand, supply can be increased by increasing labour productivity and by attracting more personnel.

Automation and robotisation, for example, can assume standardised tasks. In addition, task specialisation could help relieve the workers in the occupations with the highest scarcity, with more tasks being handled by auxiliary workers.

These two trends increase labour productivity and reduce demand for the labour that is needed to accomplish the tasks. Finally, shifting work from the construction site to a plant can increase the supply of labour to include people from outside the construction industry, thereby increasing the supply of labour in construction.

Bibliography

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., . . . Peacock, A. (2019). Blockchain technology in the energy sector: a systematic review of challenges and opportunities. *Renew. Sust. Energ. Rev. 100, 143-174*.

Arcadis. (2020). Kostenkengetallen Energiebesparende maatregelen bestaande woningbouw. Arcadis.

Binnenklimaat Nederland. (2022). *Programma van Eisen 'Gezonde woningen'.*

CBS. (2022). *CBS statline - Woningen; hoofdverwarmingsinstallaties, regio.*

CE Delft. (2020). *Kansen voor thermische opslagsystemen.*

CE Delft. (2021). *Factsheet Warmwaterboilers.* Delft: CE Delft. Opgehaald van https://ce.nl/wp-content/uploads/2021/04/21_Factsheet-Warmwaterboilers_DEF.pdf

CO2-emissiefactoren. (2022). *Lijst emissiefactoren - Warmtelevering*. Opgehaald van https://www.co2emissiefactoren.nl/lijst-emissiefactoren/

De Groot, S. (2020). *Economic and thermal performance of Ecovat and comparable thermal energy storage systems.* Veghel: Ecovat. Opgehaald van https://www.ecovat.eu/wp-content/uploads/2020/06/20200609-Ecovat_comparison_Final_ENG-gecomprimeerd.pdf

De Heer, H., Fiorini, L. v., & Winters, E. (2022). *Collectieve zelfconsumptie: een bouwsteen om het maatschappelijk draagvlak voor de energietransitie te vergroten?* TKI Uerban Energy.

De Koning, N., Kooger, R., Hermans, L., & Tigchelaar, C. (2019). *Aardgasvrij wonen: drijfveren en barrières van bewoners.* TNO 2019 P12006.

Dinkelman, D., & Menkveld, M. (2021). *Berekening duurzaamheid van warmtebronnen.* Utrecht: TNO. Opgehaald van https://repository.tno.nl/islandora/object/uuid%3A52295d38-8688-493b-a571-ef5ccfb4a59f

DNE Research. (2021). *Nationaal Warmtenet Trendrapport 2021.* Dutch New Energy. Opgehaald van https://www.dutchnewenergy.nl/trendrapporten/nationaal-warmtenet-trendrapport-2021/

ETIP. (2020). *etip-pv.eu.* Opgehaald van https://etip-pv.eu/publications/fact-sheets/

Florence School of Regulation. (2021). *Peer-to-Peer, Energy Communities, Legal Definitions and Access to Markets.*

Fortes. (2018). *Aquaheat stations prijslijst - Warmte units en toebehoren.* Opgeroepen op September 2022, van https://fortes-es.nl/wp-content/uploads/2018/08/aquaheat-stations-prijslijst-2018.pdf

Goldschmidt, G., Wagner, L., Pietzecker, R., & Friedrich, L. (2021). Technological learning for resource efficient terawatt scale photovoltaics. *Energy & Environmental Science, 14*, 5147.

Hermans, L., van Lidth, M., Klösters, M., Tigchelaar, C., & Kooger, R. (2020). *Subsidie is een suikeroom. En lening een lange man in een zwarte jas. Onderzoek naar perceptie van financieringsconstructen voor verduurzaming woning.* TNO 2020 P12193.

Hooff, W. v., Kuijers, T., Quax, R., & Witte, J. (2021). *Ruimtelijk potentieel van zonnestroom in Nederland.*

Jacobs, P. (2021). *Bijna geen enkele woning voldoet aan nieuwe WHO fijnstofnorm. TVVL.*

Jacobs, P., Vijlbrief, O., & Kemp, R. (2020). *Openbaar eindrapport MEED: Multifuncionele Energie Efficiënte Douchecabine.* TNO.

Kort, J., de Koning, N., & Kooger, R. (2020). *Onderzoek Enpuls: hoe krijg je bewoners warm voor een warmtenet?* TNO 2020 P11460.

Lensink, S., & Schoots, K. (2021). *Eindadvies basisbedragen SDE++2022.* PBL.

Lenzmann, F., Kester, J., Lindfors, S., Lampinen, V., Radavicius, T., & Regrettier, T. (2021). *Intermediate Environmental Evaluation (Deliverable report D8.2, EU Project HighLite).*

Moerman, A., Blokker, M., van der Blom, E., & van Veelen, I. (2016). *Inzicht in efficiënctie van warmtapwaterbereiding voor diversiteit aan huishoudens.* KWR.

Mulder, G., Nauta, J., Klerks, S., & Donkervoort, R. (2021). *In de volgende versnelling naar een klimaatneutrale gebouwde omgeving – Slimmer, goedkoper en efficiënter aan de hand van contingenten.*

PBL. (2021). *Functioneel ontwerp Vesta Mais 5.0.* Den Haag: Planbureau voor de Leefomgeving. Opgehaald van https://www.pbl.nl/sites/default/files/downloads/pbl-2021-functioneel-ontwerp-vesta-mais-5.0-4583.pdf

PBL. (2021). *Klimaat- en energieverkenning 2021. PBL-publicatienummer: 4681.*

Pothof, I., Vreeken, T., & Meerkerk, M. v. (2022). *Field measurements on lower radiator temperatures in existing buildings. Manuscript for Energy and Buildings.*

Rooijers, F., & Jongsma, C. (2020). *Verkenning ontwikkeling CO2-vrije flexibele energietechnieken.* CE Delft.

RVO. (2022). *Standaard en streefwaarden voor woningisolatie*. Opgeroepen op September 2022, van https://www.rvo.nl/onderwerpen/wetten-en-regels-gebouwen/standaard-streefwaarden-woningisolatie

Schepers, B., & Dehens, J. (2020). *Kansen voor thermische opslagsystemen.* Delft: CE Delft.

Segers, R., Niessink, R., van den Oever, R., & Menkveld, M. (2020). *Warmtemonitor 2019.* RVO.

Sinke, W., Folkerts, W., & Weeber, A. (2021). *Zonpositief: Zonne-energie op weg naar impact.* TNO.

Theelen, M., Kester, J., Hauck, M., Spaeth, M., Kuypers, A., & Sinke, W. (2021). *Tijd voor duurzame zonne-energie.* TNO.

Topsector Energie-systeemintegratie. (2021). *Energy Hubs - Vitale knooppunten in een energiesysteem.*

Van Capellen, L., Wielders, L., & Scholten, T. (2021). *Emissiefactor elektriciteit uit fossiele bronnen.* CE Delft.

Van Hooff, W., Kuijers, C., Quax, R., & Witte, J. (2021). *Ruimtelijk potentieel van zonnestroom in Nederland.* TKI Urban Energy.

Van Petersen, D. (2021). *Kennisdossier legionella in de energietransitie.* TKI Urban Energy.

Wirth, H. (2022). *Aktuelle Fakten zur Fotovoltaik in Deutschland.* Fraunhofer ISE.

Annex
General key figures

In this section, we explain the generic key figures used to calculate housing stock, national costs and CO_2 emissions. More specific numbers and assumptions for each sub-report are provided in the separate annexes.

Housing stock

A data file of the housing stock has been prepared, which is broken down by type of home (single-family and multi-family), ownership type (private purchase, private rental and social rental) and construction-year class. The housing stock and average heat demand for these different homes were taken from the (reference homes in the) KEV 2021.

The total heat demand has been determined by multiplying home numbers by average heat demand. This was then compared with the heat demand based on the energy statistics in the Energy Savings Monitor for the Built Environment (for all energy carriers for heat). A correction factor has been determined for each focus year for the heat demand per home, so that the heat demand comes out at the statistic (heat demand for all energy carriers).

An estimate of the share of space heating in household heat consumption was taken from the Energy Savings Monitor for the Built Environment. This figure is around 80 per cent and, in this calculation, is assumed to be constant. In the Monitor, the share of domestic hot water is 18 per cent and the share of cooking is 2 per cent.

National costs

National costs have been calculated as the balance of costs and benefits for the Netherlands as a whole, excluding transactions between parties. National costs comprise:

- Investment cost per year (annuity). The initial investment costs have been converted to an annual depreciation based on a discount rate of 3 per cent
- Operating costs
- Energy costs (which decrease with energy savings)

The national additional costs have been calculated specifically – i.e. the additional costs when compared to the costs according to the assumptions in the KEV.

Calculating national costs means looking at wholesale prices (Table 3). These are the prices excluding energy tax, ODE surcharge and VAT. These additional surcharges increase tariffs for end users. As this tax brings revenue for the government, these surcharges are not counted as national costs. Grants are also not included.

The annual energy costs for natural gas and electricity have been calculated using the scenario for wholesale prices in the KEV 2021 for 2030.

Table 3 Wholesale prices per energy carrier from the KEV 2021

Wholesale price per energy carrier	Unit	2020	2030
Natural gas	Euro2020 per m^3	0.13	0.22
Electricity	Euro2020 per kWh	0.037	0.050

CO_2 emissions

Decreasing demand for natural gas and/or increasing demand for electricity gives rise to a change in CO_2 emissions. Here, we look at both direct and indirect emissions:

- Direct CO_2 emissions: emissions directly from the built environment
- Indirect CO_2 emissions: emissions outside the built environment sector, such as emissions in electricity generation or from heat generation for district heating grids

The Netherlands Enterprise Agency has been used as the source for the emissions factor for natural gas: 56.4 kg/GJ natural gas. The lower calorific value (LHV) of natural gas (31.65 MJ/m3) has been used for the conversion of gas consumption in m^3 to GJ.

The CBS statistic up to 2019 has been used for the emissions factor electricity. For the future, the projections used in the KEV 2021 Integral method have been used. In 2020, this is 0.25 $kgCO_2/kWh$ based on the KEV 2021 estimate. In 2030, this is 0.09 $kgCO_2/kWh$ based on the KEV 2021 estimate.

Annex A Solar PV

Key figures

The following key figures relating to the technology and market size of PV outlined in Table 4 and Table 5 have been used for the calculations in this report. For the calculation of the national (additional) costs, the average of the 2020 and 2030 LCOEs has been used to take into consideration the fact that the PV systems that will be generating electricity in 2030 will be installed over the period 2020 to 2030. An LCOE of EUR 0.069/kWh has been assumed for CCGT systems in 2030 (Rooijers & Jongsma, 2020).

For the calculation of the net emissions reduction, it has been assumed that CO_2 emissions from PV are nil (so no lifecycle emissions have been taken into consideration). The emissions factor used for CCGT plants is 0.357 g CO_2/kWh (Van Capellen, Wielders, & Scholten, 2021).

Table 4 Key figures relating to PV technology (ETIP, 2020)

	Focus year	LCOE (EUR/kWh)
PV on homes	2020	0.07
	2030	0.042
PV on non-residential buildings	2020	0.052
	2030	0.035
PV in outlying areas	2020	0.042
	2030	0.026

Table 5 Key figures relating to market size for different potential market developments in 2030. The Baseline is the potential that is used in the KEV (PBL, 2021).

	Potential market development	Electricity generation (TWh)	Additional electricity generation vs KEV estimate (TWh)
PV on homes	Baseline	8.5	-
	Doubling	17	8.5
	Technical potential	82	73.5
PV on non-residential buildings	Baseline	9.5	-
	Doubling	19	9.5
	Technical potential	98	88.5
PV in outlying areas	Baseline	5	-
	Doubling	10	5
	Technical potential	40	35

Annex B Industrialisation of renovation concepts

Key figures

The key figures for gas savings and investment costs for renovation are derived from calculations performed for the ‘Standard’ (RVO, 2022). In this context, a distinction is drawn between level 3 and 4 in accordance with the ‘Standard’ (Table 6 and Table 7). For the costs for insulation level 4 with industrialisation, 30 per cent of the investment costs for level 4 have been deducted on account of the estimate by the experts interviewed that an industrial approach, in any event by means of roof renovation, could be 20 to 40 per cent cheaper than the traditional approach. The annual investment costs (annuity) for renovations have been calculated based on the assumption of an amortisation period of 50 years and a discount rate of 3 per cent.

Table 6 The number of homes and key figures for insulation level 3 of S&T

Target group	Number of renovated homes	Saving (m^3/home/year)	Costs (EUR/home)
Multi-family– rented	1,487,214	381	5,241
Multi-family – owned	637,984	418	6,085
Single-family – rented	1,053,044	640	10,508
Single-family – owned	2,915,152	789	13,763

Table 7 The intensities and key figures for insulation level 4 of S&T with 30 per cent cost reduction through industrialisation

Target group	Number of renovated homes	Saving (m^3/home/year)	Costs (EUR/home)
Multi-family – rented	1,487,214	672	13,911
Multi-family – owned	637,984	757	16,663
Single-family – rented	1,053,044	1,049	21,007
Single-family – owned	2,915,152	1,362	30,046

Impact

Current technology

When it comes to the current technology, we assume that the homes are improved to insulation level 3 of the ‘Standard’ with the traditional approach. In terms of the potential market developments, Table 8 shows how many homes are renovated, what CO_2 reduction is achieved through energy savings and what the national costs are.

Table 8 Impact of the potential market developments of home renovations to insulation level 3 of the ‘Standard’ with the traditional approach.

	Single-family homes		Multi-family homes	
Market development	Owned	Rental	Owned	Rental
Number of homes				
Natural opportunity	583,030	210,609	127,597	297,443
Technical potential	2,915,152	1,053,044	637,984	1,487,214
Gas savings per year				
Natural opportunity	15	4	2	4
Technical potential	73	21	8	18
CO_2 reduction in Mt				
Natural opportunity	0.8	0.2	0.1	0.2
Technical potential	4.1	1.2	0.5	1.0
Saving on energy costs for gas in billions of euros				
Natural opportunity	0.10	0.03	0.01	0.03
Technical potential	0.52	0.15	0.06	0.13
National costs in billions of euros per year				
Natural opportunity	0.4	0.1	0.0	0.1
Technical potential	2.2	0.7	0.2	0.5

Innovative technology

For the calculations of the innovative technology, the homes are renovated using the industrial approach, which includes renovation to insulation level 4 of the ‘Standard’. Here too, the additional costs have been derived from the ‘Standard’; the costs were then reduced by 30 per cent as indicated by the interviews. Table 9 thus shows the impact of not only renovating more, but of renovating better. By way of comparison, the national costs are also shown for renovation to level 4 with the traditional approach, without the 30 per cent reduction in costs.

Table 9 Impact of the potential market developments for different target groups in the case of renovation to level 4 of the ‘Standard’ with an industrial approach.

Market development	Single-family homes Owned	Single-family homes Rental	Multi-family homes Owned	Multi-family homes Rental
Number of homes				
Natural opportunity	583,030	210,609	127,597	297,443
Technical potential	2,915,152	1,053,044	637,984	1,487,214
Gas savings per year				
Natural opportunity	25	7	3	6
Technical potential	126	35	15	32
Direct CO_2 reduction in Mt				
Natural opportunity	1.4	0.4	0.2	0.4
Technical potential	7.1	2.0	0.9	1.8
Saving on energy costs for gas in billions of euros				
Natural opportunity	0.2	0.0	0.0	0.0
Technical potential	0.9	0.2	0.1	0.2
National costs in billions of euros per year				
Natural opportunity	1.0	0.3	0.1	0.2
Technical potential	5.1	1.4	0.6	1.2
National costs with innovation in billions of euros per year				
Natural opportunity	0.7	0.2	0.1	0.2
Technical potential	3.6	1.0	0.4	0.9

Annex D Heat pumps

Key figures

A distinction has been drawn between all-electric air-water heat pumps, all-electric ground-based heat pump systems and hybrid systems comprising an air heat pump and a gas boiler. The key figures used for investment costs, maintenance costs and average efficiency over a heating season (the SPF, Seasonal Performance Factor) have been taken from the TNO Technology fact sheets.[31] This is an average based on various literature sources. Assumptions for the 'current technology' are set out in Table 10. The table also provides the costs of the CH boiler used as a reference when calculating the additional costs. The costs of the CH boiler have been taken from the 'End user costs for homes' TNO dashboard.[32]

Table 10 Key figures used in the impact calculation (SPF: Seasonal Performance Factor)

Technology	Parameter	Unit	Value
All-electric air-source heat pump	Average investment	Euro2020/home	8,349
	Maintenance costs	Euro2020/home/year	141
	SPF space heating	-	3.1
	SPF domestic hot water	-	2.0
Hybrid system with CH boiler and air-source heat pump	Average investment	Euro2020/home	5,150
	Maintenance costs	Euro2020/home/year	193
	SPF space heating	-	3.5
	SPF domestic hot water	-	2.0
All-electric ground-source heat pump	Average investment	Euro2020/home	13,873
	Maintenance costs	Euro2020/home/year	107
	SPF space heating	-	4.0
	SPF domestic hot water	-	2.5
CH boiler	Average investment	Euro2020/home	1,776
	Maintenance costs	Euro2020/home/year	50

---

[31] https://energy.nl/datasheets/

[32] https://energy.nl/tools/dashboard-eindgebruikerskosten/

The point of departure is that the use of an all-electric heat pump will make the home free of natural gas, i.e. a 100 per cent saving on natural gas for space heating and domestic hot water. This nevertheless requires electricity. The electricity demand is calculated as follows:

$$Electricity\ demand = \left(\frac{space\ heating\ heat\ demand}{SPF\ for\ space\ heating}\right) + \left(\frac{domestic\ hot\ water\ heat\ demand}{SPF\ for\ domestic\ water}\right)$$

For a hybrid heating system, it is assumed that the proportion of the heat demand for space heating and domestic hot water met by the heat pump is 50 per cent. Various configurations involving hybrid systems are possible; the proportion from the heat pump may be higher or lower, depending on the thermal capacity of the heat pump and the respective home. Here, it has been assumed that the heat pump in an average hybrid configuration in existing homes covers a 50 per cent proportion of the heat demand.

The indirect CO_2 emissions in the electricity sector have been calculated using the national emissions factor for electricity generation in 2030 in the KEV. The CO_2 reduction due to natural gas savings has been calculated using the emissions factor for natural gas (emissions factors are provided in the annex entitled General key figures).

The annual investment costs (annuity) for heat pumps have been calculated on the assumption of an amortisation period of 20 years and a discount rate of 3 per cent.

Impact

Current technology

The calculated impacts of replacing CH boilers with heat pumps are shown in Table 11. The table starts with the number of homes for each potential market development. The Baseline is the number of homes for which the KEV assumes that the current CH boiler will be replaced by a heat pump by 2030. The market developments show the additional number of homes in which a CH boiler is replaced when compared to the KEV. The total number of homes into which an all-electric heat pump is installed is thus a sum of the total number of homes under the Baseline and the market development in question.

The table then shows the outcomes of this replacement for direct and indirect CO_2 emissions reduction for national costs and additional national costs. The costs are the additional costs when compared to replacing the CH boiler. Only the number of heat pumps installed is different for each market development. Here too, the results of the market developments are shown as the additional impact when compared to the KEV, that is to say the additional emissions reduction and additional national costs.

Table 11 The impact of the replacement of CH boilers with heat pumps in 2030 for different potential market developments. The number of homes and the impact in the potential market developments is the number of additional homes/impact when compared to the Baseline.

Market development	All-electric air-water heat pump		All-electric ground-source heat pump		Hybrid heat pump	
	Single-family homes	Multi-family homes	Single-family homes	Multi-family homes	Single-family homes	Multi-family homes
Number of homes						
Doubling	26,242	4,500	26,242	4,500	26,242	4,500
Natural opportunity	3,100,519	1,587,285	3,100,519	1,587,285	3,100,519	1,587,285
Technical potential	4,650,778	2,380,927	4,650,778	2,380,927	4,650,778	2,380,927
Direct CO_2 reduction in Mt						
Doubling	0.1	0.0	0.1	0.0	0.0	0.0
Natural opportunity	7.0	1.8	7.0	1.8	3.5	0.9
Technical potential	10.5	2.7	10.5	2.7	5.3	1.4
Indirect CO_2 emissions in Mt						
Doubling	0.0	0.0	0.0	0.0	0.0	0.0
Natural opportunity	-1.1	-0.3	-0.9	-0.2	-0.5	-0.1
Technical potential	-1.7	-0.4	-1.3	-0.3	-0.8	-0.2
National costs in billions of euros per year						
Doubling	0.0	0.0	0.0	0.0	0.0	0.0
Natural opportunity	2.8	1.3	3.7	1.8	2.4	1.0
Technical potential	4.2	1.9	5.6	2.7	3.6	1.6
Additional national costs in billions of euros per year						
Doubling	0.0	0.0	0.0	0.0	0.0	0.0
Natural opportunity	1.6	0.8	2.5	1.3	1.2	0.6
Technical potential	2.3	1.2	3.7	2.0	1.7	0.9

Innovative technology

Table 12 shows the additional effects that are realised when compared to the KEV with an improved efficiency from air-source heat pumps of 7.5 per cent and lower investment costs (by 15 per cent). This is visible in the impacts 'with innovation'. The numbers of heat pumps within the market developments are otherwise the same.

Table 12 The impact of the replacement of CH boilers with innovative all-electric heat pumps for different potential market developments. The number of homes in the potential market developments is the number of additional homes when compared to the Baseline.

Market development	All-electric air-water heat pump Single-family homes	Multi-family homes	All-electric ground-source heat pump Single-family homes	Multi-family homes	Hybrid heat pump Single-family homes	Multi-family homes
Number of homes						
Doubling	26,242	4,500	26,242	4,500	26,242	4,500
Natural opportunity	3,100,519	1,587,285	3,100,519	1,587,285	3,100,519	1,587,285
Technical potential	4,650,778	2,380,927	4,650,778	2,380,927	4,650,778	2,380,927
Direct CO_2 reduction in Mt						
Doubling	0.1	0.0	0.1	0.0	0.0	0.0
Natural opportunity	7.0	1.8	7.0	1.8	3.5	0.9
Technical potential	10.5	2.7	10.5	2.7	5.3	1.4
Indirect CO_2 emissions with innovation in Mt						
Doubling	0.0	0.0	0.0	0.0	0.0	0.0
Natural opportunity	-1.0	-0.3	-0.8	-0.2	-0.5	-0.1
Technical potential	-1.5	-0.4	-1.2	-0.3	-0.7	-0.2
National costs with innovation in billions of euros per year						
Doubling	0.0	0.0	0.0	0.0	0.0	0.0
Natural opportunity	2.5	1.1	3.2	1.5	2.2	1.0
Technical potential	3.7	1.7	4.9	2.3	3.3	1.4
Additional national costs with innovation in billions of euros per year						
Doubling	0.0	0.0	0.0	0.0	0.0	0.0
Natural opportunity	1.3	0.7	2.0	1.1	1.0	0.5
Technical potential	1.9	1.0	3.0	1.6	1.5	0.8

Annex E Output systems

The key figures in Table 13 have been used for the investment costs in the calculations in this sub-report. In view of the fact that (LT) output systems are an integral component of (LT) heating systems, the same number of homes has been assumed for the market size as has been assumed for LT district heating grids (Table 14).

Table 13 Key figures relating to the technology (taken and rounded from (Arcadis, 2020))

	CAPEX (EUR)
Convector	4.500
Floor heating	11.500

Table 14 Key figures relating to the market size of different potential market developments in 2030, derived from the 'District heating grids' sub-report.

Target group	Potential market development	Additional number of homes when compared to the KEV estimate
Single-family homes	Doubling	47,700
	Technical potential	3,553,870
Multi-family homes	Doubling	36,495
	Technical potential	2,524,824

Annex F Domestic hot water systems

The key figures in Table 15 relating to the technology used have been used in the calculations in this report. Considering the point of departure that our analysis is based on a separate domestic hot water system (as required in homes that are connected to LT district heating grids), the same number of homes has been assumed for the market size as was assumed for LT district heating grids (Table 16).

Table 15 Key figures relating to the technology

	CAPEX (EUR)	OPEX (%)	Electricity consumption (kWh per GJ of heat)
Instant water heater	1.500	3	173
w/w heat pump with heat recovery	4500	3	35

Table 16 Key figures relating to the market size of different potential market developments in 2030, derived from the ‘District heating grids’ sub-report.

Target group	Potential market development	Additional number of homes when compared to the KEV estimate
Single-family homes	Doubling	47,700
	Technical potential	3,553,870
Multi-family homes	Doubling	36,495
	Technical potential	2,524,824

Annex G Ventilation systems

When a home is due for renovation, it is often draught proofed in an attempt to reduce heat loss, which in turn gives rise to energy savings. A ventilation system can then be used to ensure an adequate supply of fresh air. A ventilation system results in an incoming air flow into the home that needs to be heated during the heating season. The impacts of two technologies have been determined in this sub-report:

- Current technology: demand-controlled mechanical ventilation
- Innovative technology: demand-controlled balanced ventilation with heat recovery via air distribution (single-family home) or decentralised ventilation (multi-family home).

The reference situation is a home with a natural gas-fired CH boiler and natural ventilation.

CO$_2$ emissions

A heat-balance model for homes developed by TNO suggests that draught proofing helps to reduce heat loss by 0.03 GJ/m^2 of floor area.[33] The same model assumes a heat loss of 1.84 GJth/year for a demand-controlled mechanical ventilation system. In the case of balanced ventilation with heat recovery, heat from the outgoing ventilation air is recovered to heat the incoming air, thereby reducing heat loss by 70 per cent, equivalent to 0.55 GJth/year. With 100 per cent boiler efficiency, the natural gas saving is equivalent to the reduction in heat loss. The following applies:

Savings total = heat loss reduction achieved with draught proofing – heat loss through the ventilation system

The electricity consumption of the ventilation system has been calculated using the power (calculated using the assumptions in NTA8800, Table 17) and the number of hours operating in off, low, medium and high. Data from the Housing Study 2018 have allowed three user profiles to be prepared for use of ventilation systems. As a result, the average number of operating hours for each ventilation level could be derived, Table 18. By using demand control, the ventilation system operates only when it is needed, such as when the CO$_2$ level in the room is too high. This helps to reduce the number of operating hours, thereby saving on electricity. According to this calculation, demand-controlled mechanical ventilation consumes 31 kWh/year, while the figure for demand-controlled balanced ventilation is 70 kWh/year.

Table 19 provides an overview of positive and negative energy costs.

Table 17 Ventilation power (W) (direct current)

Ventilation power	Off	Low	Medium	High
Mechanical ventilation (W)	0	6.3	12.5	18.8
Balance with heat recovery (W)	0	14.1	28.1	42.2

Table 18 Operating hours of ventilation system

System status:	Hours per year without demand control	Hours per year with demand control

---

[33] Averages from the CBS housing stock statistics have been used to distinguish the average area for each type of home.

Off	2011	5222
Low	5368	2684
Medium	528	264
High	854	590
Total	8760	8760

Table 19 Energy costs (positive) and energy costs saved (negative) for ventilation and draught proofing

Cost type	Technology	Result for 2030
Natural opportunity		
Single-family home		
Energy costs for natural gas in billions of euros	Mechanical ventilation with demand control	0.008
	Balanced ventilation with heat recovery	0.002
	Draught proofing	-0.018
Energy costs in billions of euros	Mechanical ventilation with demand control	0.001
	Balanced ventilation with heat recovery	0.002
Multi-family home		
Energy costs for natural gas in billions of euros	Mechanical ventilation with demand control	0.004
	Balanced ventilation with heat recovery	0.001
	Draught proofing	-0.005
Energy costs in billions of euros	Mechanical ventilation with demand control	0.0005
	Balanced ventilation with heat recovery	0.001
Technical potential		
Single-family home		
Energy costs for natural gas in billions of euros	Mechanical ventilation with demand control	0.039
	Balanced ventilation with heat recovery	0.012
	Draught proofing	-0.090
Energy costs in billions of euros	Mechanical ventilation with demand control	0.005
	Balanced ventilation with heat recovery	0.010
Multi-family home		
Energy costs for natural gas in billions of euros	Mechanical ventilation with demand control	0.020
	Balanced ventilation with heat recovery	0.006
	Draught proofing	-0.026
Energy costs in billions of euros	Mechanical ventilation with demand control	0.002
	Balanced ventilation with heat recovery	0.005

National costs

The points of departure for the costs of ventilation systems are shown in Table 20. The costs shown in the table are investments at a natural point time, excluding VAT. The costs of demand control are included as part of the investment.

The investment costs for mechanical ventilation with demand control for single-family homes and multi-family homes are taken from the Arcadis cost key figures (Arcadis, 2020). The average investment for balanced ventilation with heat recovery and demand control is around 4 to 4.5 thousand euros per home, excluding VAT (Arcadis, 2020). In the case of a single-family home, it has been assumed that balanced ventilation is provided via air distribution. Based on the interviews with experts, it has been assumed that the costs would be the same as for a standard balanced ventilation system with heat recovery. For a multi-family home, it has been assumed that balanced ventilation is achieved via decentralised ventilation systems.

The (one-off) annual maintenance costs for ventilation systems have been calculated on the basis of 3 per cent of the investment costs per year. The annual investment costs (annuity) for ventilation systems have been calculated based on the assumption of an amortisation period of 20 years and a discount rate of 3 per cent.

The costs for draught proofing are based on the Arcadis cost key figures (Arcadis, 2020), whereby the average costs of four cost codes have been added together. Table 21 shows the key figures used for draught proofing.

Finally, Table 22 gives the national costs for ventilation and draught proofing.

Table 20 Investment costs and operational costs for ventilation

Technology	Home type	Parameter	Unit	Value	Arcadis cost code
Mechanical ventilation with demand control	Multi-family home	Average investment	Euros/home	3,137	171
Mechanical ventilation with demand control	Single-family home	Average investment	Euros/home	3,320	171
Balanced ventilation with heat recovery and demand control – decentralised	Multi-family home	Average investment	Euros/home	4,174	156
Balanced ventilation with heat recovery and demand control – air distribution	Single-family home	Average investment	Euros/home	4,512	110
Mechanical ventilation with demand control	Multi-family home	Operating costs	Euros/home/ year	94	-
Mechanical ventilation with demand control	Single-family home	Operating costs	Euros/home/ year	100	-
Balanced ventilation with heat recovery and demand control	Multi-family home	Operating costs	Euros/home/ year	125	-
Balanced ventilation with heat recovery and demand control	Single-family home	Operating costs	Euros/home/ year	135	-

Table 21 Investment costs and savings through draught proofing

Home type	Parameter	unit	Value	Arcadis cost code
Multi-family home	Average investment	Euros/home	268	92, 93, 94 and 95
Single-family home	Average investment	Euros/home	405	92, 93, 94 and 95
Multi-family home	Natural gas savings	GJ natural gas/home/year	2.4	92, 93, 94 and 95
Single-family home	Natural gas savings	GJ natural gas/home/year	4.3	92, 93, 94 and 95

Table 22 Investment costs and operational costs for ventilation and draught proofing

Cost type	Technology	Result for 2030
Natural opportunity		
Single-family home		
Annuity in billions of euros per year	Mechanical ventilation with demand control	0.13
	Balanced ventilation with heat recovery	0.18
	Draught proofing	0.01
Operating costs in billions of euros per year	Mechanical ventilation with demand control	0.06
	Balanced ventilation with heat recovery	0.08
Multi-family home		
Annuity in billions of euros per year	Mechanical ventilation with demand control	0.07
	Balanced ventilation with heat recovery	0.09
	Draught proofing	0.00
Operating costs in billions of euros per year	Mechanical ventilation with demand control	0.03
	Balanced ventilation with heat recovery	0.04
Technical potential		
Single-family home		
Annuity in billions of euros per year	Mechanical ventilation with demand control	0.66
	Balanced ventilation with heat recovery	0.90
	Draught proofing	0.05
Operating costs in billions of euros per year	Mechanical ventilation with demand control	0.30
	Balanced ventilation with heat recovery	0.40
Multi-family home		
Annuity in billions of euros per year	Mechanical ventilation with demand control	0.33
	Balanced ventilation with heat recovery	0.44
	Draught proofing	0.02
Operating costs in billions of euros per year	Mechanical ventilation with demand control	0.15
	Balanced ventilation with heat recovery	0.19

Annex I District heating grids

Market share

To be able to determine the number of homes for potential market developments, data relating to district heating density from the Start Analysis by PBL have been used. We have defined three heat-demand density classes based on the range: ‘Low’ <500 GJ/ha/year, ‘Medium’ 500 to 1000 GJ/ha/year and ‘High’ >1500 GJ/ha/year. The number of homes within these class limits in 2020 was then determined (Table 23). The potential of ‘High’ and ‘Medium’ has been taken for the technical potential. In addition, the number of single-family homes and multi-family homes is also indicated.

Table 23 Number of homes by heat-demand density class used to determine the potential of district heating grids

Building density	Number of homes (existing stock in 2020)	Percentage of number of homes	Number of single-family homes	Number of multi-family homes
High	1,791,541	23%	483,109	1,308,432
Medium	4,371,358	56%	3,118,461	1,252,897
Low	1,598,936	21%	1,390,137	208,799
Total	**7,761,835**	**100%**	4,991,707	2,770,128

CO_2 emissions reduction

The direct CO_2 reduction from switching from natural gas to the primary MT heat source (Table 24) has been taken into consideration for the net CO_2 reduction in the case of an MT grid (‘current technology’) when compared to HR boilers. It has been assumed that heat production from the MT source is not free of CO_2; the calculation is based on the emissions factor of a residual heat source of 8.8 kg of CO_2/GJ of heat.[34]

In addition, the additional CO_2 emissions from the use of auxiliary boilers (12 kg CO_2/GJ) have also been taken into consideration. The CO_2 emissions from auxiliary boilers have been determined by assuming that 20 per cent of annual heat demand is met by auxiliary boilers operating on natural gas (i.e. auxiliary boilers supply at peak demand and maintenance times). This 20 per cent is based on the VESTA Functional Draft (PBL, 2021).

Considering that both MT sources and auxiliary boilers are not CO_2-free heat sources, the CO_2 emissions per GJ have been calculated as associated with the heat production. To this end, it has been assumed that the total pipe loss in the grid is 25 per cent (according to the interviews).

---

[34] https://www.co2emissiefactoren.nl/lijst-emissiefactoren/

For reference: CO_2 savings, district heating grid when compared to CH boiler operating on natural gas

Figure I 4 shows that the CO_2 savings of district heating grids when compared to a CH boiler operating on natural gas vary considerably according to the grid (DNE Research, 2021). Emissions are an average of 28.7 kg CO_2/GJ (average of 27 large grids), which is equivalent to an average saving of around 50 per cent when compared to a CH boiler operating on natural gas. By way of comparison: the savings found for MT grids in this report are 55 per cent. Important determining factors for emissions reduction are 1. whether or not the heat is generated with combined heat and power plants, thereby saving primary fuel because these plants also produce electricity at the same time, and 2. the proportion of the heat supply covered by an auxiliary boiler operating on natural gas. The higher the proportion of natural gas-fired ('heat-only') boilers in heat production, the lower the reduction in emissions when compared to the CH boiler. Heat from biomass heat plants is considered renewable heat and has no emissions factor. There is an emissions factor for residual heat sources. This is because these must be decoupled from power plants or industry for which electricity is required, which causes indirect CO_2 emissions.

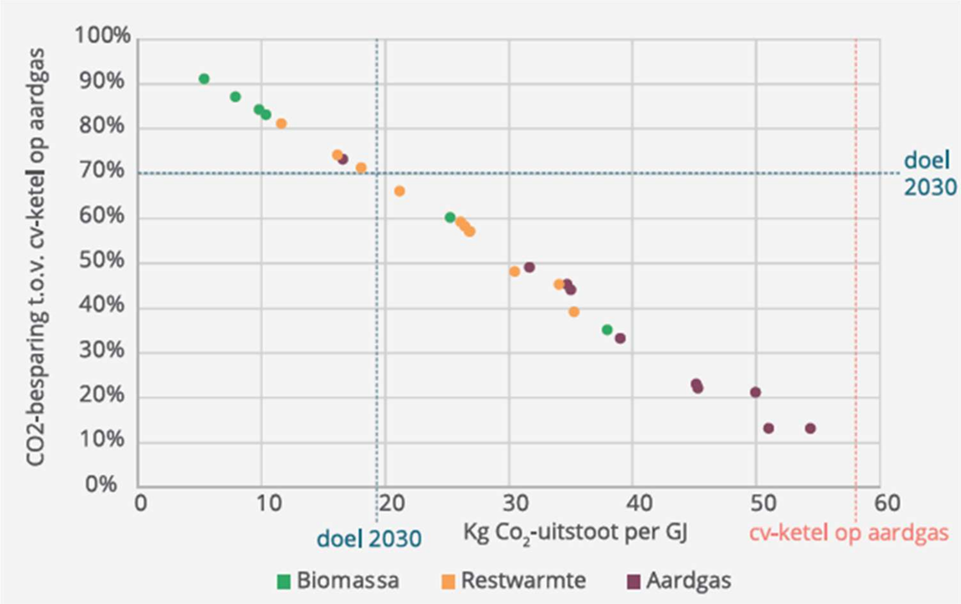


Figure I 4 CO_2 savings, district heating grid compared to CH boiler operating on natural gas (DNE Research, 2021). This is based on the heat labels from heat companies. Emissions are an average of 28.7 kg CO_2/GJ (average of 27 large grids), which is equivalent to an average saving of around 50 per cent when compared to a CH boiler operating on natural gas. Green = biomass; orange = residual; and purple = natural gas.

In the MT-grid configuration, it has also been assumed that domestic hot water is directly supplied with heat from the main heat source or auxiliary boilers. The temperature of the heat does not need to be upgraded first (there is no central heat pump) if the supply temperature is at least 60 degrees.

CO_2 reduction from switching from natural gas to the primary LT heat source has been taken into consideration for the net CO_2 reduction in the case of an LT grid ('innovative technology') when compared to HR boilers. It has been assumed that heat production from the LT source is entirely free of CO_2. This could be aquathermal or residual heat. There are no auxiliary boilers in this heating system. The pipe loss is lower than in the case of MT grids – the point

of departure here is 15 per cent heat loss, based on the interviews. In the case of LT grids, however, pipe loss has no impact on CO_2 reduction, as there are no CO_2 emissions from the main heat source, and there are no auxiliary boilers.
Domestic hot water in an LT grid can be heated by an individual system, such as a booster heat pump, an instant water heater (a type of geyser) or an electric boiler. The interviews show that, in practice, the instant water heater is chosen most, in some cases because of the lower investment costs when compared to a booster heat pump, but also because of the higher efficiency when compared to an electrical boiler. The point of departure for the LT grid is thus the assumption that domestic hot water is heated by an instant water heater. This system does produce indirect CO_2 emissions, but consumption by the system may be as much as 40 per cent[35] lower than for an electrical boiler (which has an average efficiency of 95 per cent (CE Delft, 2021)).

Table 24 Technical potential of CO_2 reduction by district heating grids and CH boilers

Technical potential for CO_2 reduction	MT grids	LT grids
Net CO_2 reduction	**6.0**	**10.3**
CO_2 reduction, main heat source compared to HR boiler	9.3	11.0
CO_2 emissions, auxiliary boiler on gas	-2.3	-
CO_2 emissions, pipe loss	-1.0	-
Indirect CO_2 emissions, domestic hot water	-	-0.6

Key cost figures

The average cost per home equivalent (EUR/WEQ) has been calculated using the data for each district from the Start Analysis by PBL on the investment costs of MT district heating grids. We have included the following cost items in the cost of MT district heating grids.

- Costs, primary grid and lateral lines to secondary distribution grid
- Costs, secondary distribution grid
- Costs, heat transfer stations
- Costs, sub-stations
- Costs, auxiliary boilers on gas

These are shown as a function of total energy demand for heat (GJ/ha/year) in Figure I 5.

There are two differences with the cost of LT grids. Firstly, there are no auxiliary boilers in the LT grid. Secondly, there are additional costs for each home for the domestic water supply.

In the case of the LT grid, an instant water heater for domestic hot water heating has been included in the investment costs. The costs of electronic output systems applicable for collective heat systems have been used to determine an average key cost figure here. In this system type, an instant water heater is integrated with the output system for district heating. The costs of these vary from between EUR 1100 to EUR 1900 (Fortes, 2018). The average investment costs for this are around EUR 1500. These costs have been added to the costs per home equivalent.

---

[35] https://www.duurzaambouwloket.nl/maatregel/doorstroomboiler

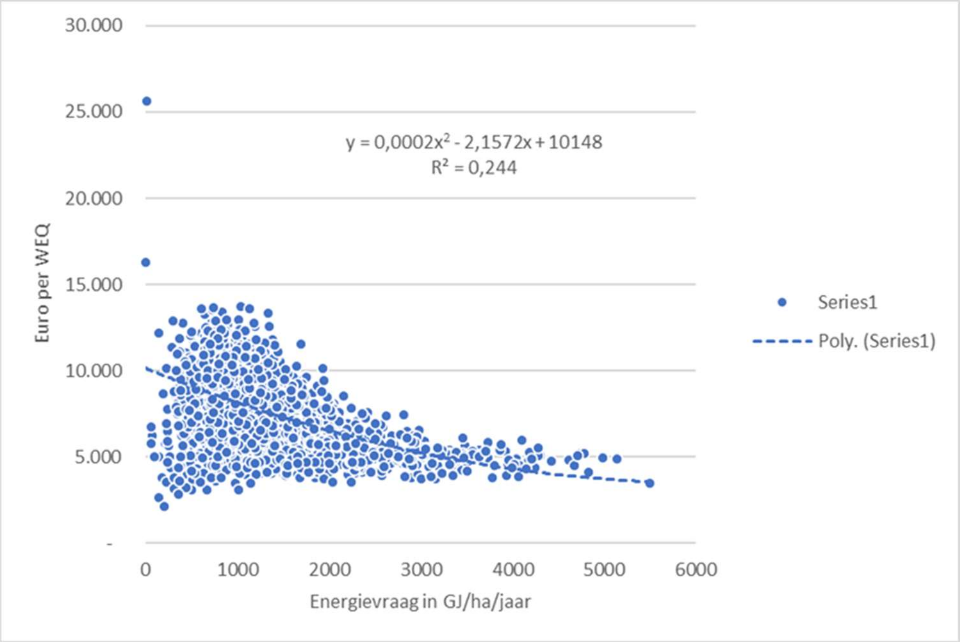


Figure I 5 National investment costs for MT district heating grid systems expressed in EUR/home equivalent based on data for each district from the Start Analysis by PBL.

The annual amortisation (annuity) for the district heating grid has been calculated based on the assumption of an amortisation period of 50 years and a discount rate of 3 per cent. The maintenance costs have been calculated on the basis of 3 per cent of the investment costs per year. For heat, a reference natural gas boiler with 87 per cent efficiency (Dinkelman & Menkveld, 2021) has been assumed on the basis of the production costs for heat. Table 25 provides an overview of all of these costs.

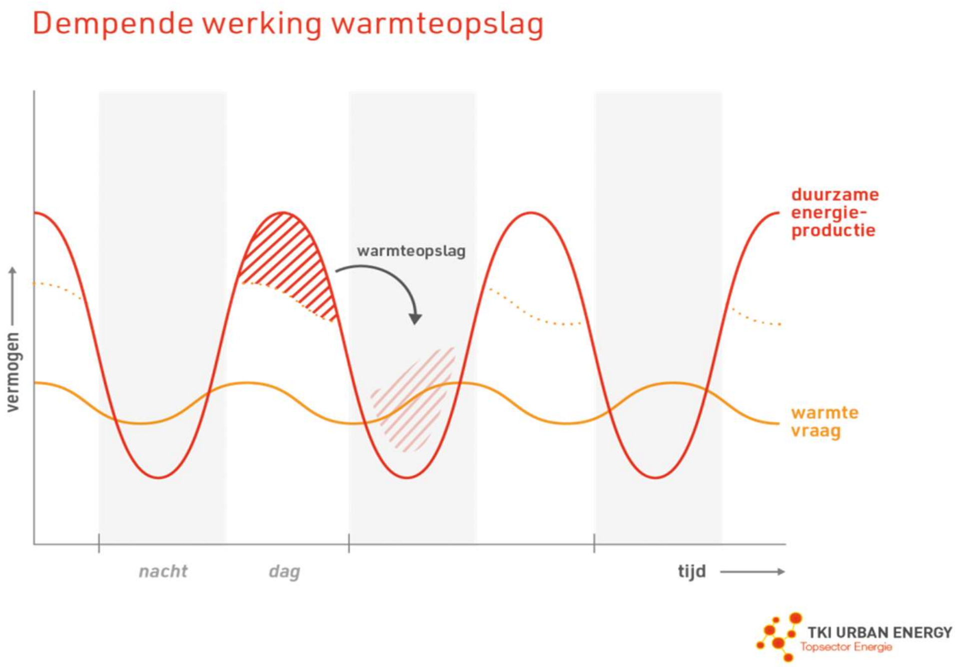
Table 25 Cost breakdown for district heating grids and CH boilers

Cost breakdown	MT grids Billions of euros per year	LT grids Billions of euros per year
National costs, district heating grid	**4.12**	**4.59**
Annuity, district heating grid	1.44	1.68
Operating costs, district heating grid	1.11	1.30
Energy costs, district heating grid	1.58	1.60
National costs, CH boilers (reference)	**1.82**	**1.82**
Annuity, CH boilers	0.42	0.42
Operating costs, CH boilers	0.30	0.30
Energy costs, CH boilers	1.10	1.10

Annex J Large-scale heat storage

Key figures

Heat storage allows peak demand to be covered instead, replacing the need for auxiliary boilers operating on natural gas; in addition, temporary storage (day/night) and seasonal storage can also be used. As a consequence, more renewable heat can be used, thus saving on natural gas. The following figure shows the principle for storing renewable energy to be used when generation falls and demand is high.[36]



The amount of storage volume required (expressed in m^3 per home) to store 25 per cent of the annual heat demand (an assumption based on (De Groot, 2020)) and thereby realise additional renewable heat utilisation has been assessed. The energy density for heat storage in water with a temperature difference to the environment of 50ºC is 0.21 GJ/(m^3 K), as the specific heat of water is 4.2 kJ/(kg K).

A multi-family home has a heat demand (for space heating and domestic hot water) of 20.4 GJ per year. For this, the average was taken from the KEV energy statistics for households. By contrast, a single-family home has a higher heat demand of 40.2 GJ per year (for space heating and domestic hot water).

The point of departure is an efficiency for heat storage of 75 per cent for storage in an aquifer and 90 per cent for tank storage (Schepers & Dehens, 2020). The remainder of the heat is lost during storage. The storage volume required for the two types of home has been calculated on the basis of these assumptions (see Table 26).

---

[36] https://www.topsectorenergie.nl/tki-urban-energy/kennisdossiers/warmteopslag

The percentage reduction in heat demand for each natural gas-fired home and the emissions factor for natural gas have been used to calculate the natural gas saving in m^3 and the reduction in CO_2 emissions.

The study by (De Groot, 2020) considered the specific investment costs (CAPEX) of the storage section of the system. These costs are expressed as specific investment costs in euros per m^3 of storage. These costs have been converted to the costs per home using the storage volumes required for each home. Assumptions are shown in Table 26.

Table 26 Assumptions for cost calculation per home for heat storage for two storage technologies, with a distinction between single-family and multi-family homes.

Technology	Aquifer	Above-ground storage tank
Specific investment costs (CAPEX) for storage (EUR/m^3)	10	100
Average heat demand, single-family home (GJ/year)	40.2	40.2
Average heat demand, multi-family home (GJ/year)	20.4	20.4
Efficiency, heat storage	75%	90%
Storage volume required per single-family home (m^3)	64	53
Storage volume required per multi-family home (m^3)	33	27
CAPEX investment per single-family home (thousands of euros/home)	0.6	5.3
CAPEX investment per multi-family home (thousands of euros/home)	0.3	2.7

The annual investment costs (annuity) for heat storage have been calculated based on the assumption of an amortisation period of 50 years and a discount rate of 3 per cent.

The maintenance costs have been calculated on the basis of 0.75 per cent of the investment costs per year for tank storage (De Groot, 2020). On the basis of the same study, no maintenance costs have been calculated for storage in an aquifer.

An overview of the national costs is provided in Table 27.

Table 27 Cost breakdown for the technical potential of heat storage

Cost breakdown	Storage in aquifer Billions of euros per year	Tank storage Billions of euros per year
National costs	**-0.2**	**0.9**
Annuity	0.1	1.0
Operating costs	0	0.2
Energy costs saved, natural gas	-0.3	-0.3