Who is paying for decarbonizing the Dutch residential sector? A detailed cost-benefits analysis of the Dutch ambitions to phase out natural gas

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Abstract
The Netherlands, in which 92 % of houses are heated by natural gas, has the ambition to phase out residential natural gas consumption completely by 2050. Municipalities are tasked to draw up plans for each neighbourhood on how and when they transition to become carbon neutral. Minimizing societal costs is the main criterion for selecting technical strategies.

Societal costs reflect effects on society as a whole, but they do not reflect the actual costs and benefits for each individual stakeholder. We determined these costs and benefits for homeowners, tenants, landlords and the national government. This resulted in a large dataset for a variety of dwelling types which are split based on typology, construction period, energy performance, ownership and energy behaviour.

Based on analysis of this data, we conclude that none of the strategies to phase out natural gas are cost effective for homeowners in 2020. Actions to stimulate cost reduction and changes in energy taxation help to improve this for 2030. We concluded that different decarbonisation options do not receive equal support from the government. Explicit and implicit benefits favour district heating and renewable gas options over all-electric options. Regulations, not necessarily designed with the energy transition in mind, have a large effect on the distribution of cost and benefits between actors. Investments in energy efficiency for example are uneconomical for landlords, since rental laws prevent them from increasing the rent to compensate for their costs.

The most economical way to reach the goal of 1.5 million natural gas free dwellings in 2030 is to prioritize well-insulated dwellings over inefficient dwellings, since the cost and benefits for installations are more favourable in these houses. Using this approach, it is more cost effective to reach large numbers of renovations quicker. However, investments in energy efficiency serve multiple purposes, such as alleviating energy poverty and reducing the demand for scarce (renewable) energy sources. Consequently, a different prioritization than one from a pure financial standpoint may be desirable.

Introduction
In the Netherlands, the Paris Accords of 2015 have been further detailed by the Dutch Climate Accord ('Klimaatakkoord') (Klimaatakkoord, 2019). The Dutch Climate Accord describes the national ambition that all dwellings, of which 92 % of houses are heated by natural gas, are to phase out residential natural gas consumption towards a completely 'gas-free' housing sector in 2050 (Tigchelaar, et al., 2019).

In order to achieve the goal of a carbon neutral energy system for the built environment by 2050, Dutch municipalities have been tasked to draw up plans for transitioning each neighbourhood's energy system towards a carbon neutral one. Since space heating of residential buildings makes up most of the energy consumption in the Dutch built environment, plans are focussing on making houses more efficient. In choosing between various technical solutions to the tasked energy transition, minimizing the societal costs is the most important criterion.

'STARTANALYSE': NATIONAL COSTS OF ENERGY TRANSITION STRATEGIES

Due to the high complexity and required systems thinking of the task at hand for municipalities, the Dutch national government tasked the Netherlands Environmental Assessment Agency (PBL) to provide helpful, technical information in order to facilitate decision making. This task took shape in the Startanalyse('Starting Analysis') – a holistic cost optimization analysis performed with the multi-actor VESTA-MAIS energy model, part of a wider approach named the 'Leidraad' ('The Guideline') The Startanalyse defined several technological energy transition scenarios, such as the implementation of electric heat pumps or the realization of a sustainable heat network and calculated a series of indicators for each individual neighbourhood in the Netherlands for each strategy. (ECW, 2022)

Key among the indicators used in the Startanalyse are the national, or societal, costs of each strategy. National costs are defined by PBL as the financial effects as a result of policy implementation, i.e., the net sum of financial costs, savings and benefits in one single indicator. This national cost indicator was utilized by PBL to select the most cost-effective technical strategy for transitioning the heating of dwellings in each individual neighbourhood in the Netherlands, which provided the basis for Dutch municipalities to draw up their plans. However, a major downside of this approach was that these national costs do not reflect the actual monetary costs and benefits for each individual stakeholder involved in the energy transition, which is an essential insight required to evaluate the viability of these modelled technical scenarios.

COSTS AND BENEFITS OF END-USERS

Independent research and technology organisation TNO was tasked by the Dutch government to strengthen PBLs Startanalyse by providing these expected costs for stakeholders such as homeowners, tenants, landlords and the national government. These actual 'end-user' costs are defined as a balance of costs and benefits of the required initial investments, running costs, financial benefits and energy service benefits (expressed in monetary value). The goal of this project was threefold: (1) to map the potential – in terms of energy savings – of the strategies included in the Startanalyse, (2) to gauge the amount of subsidies required to carry out the various technological approaches and (3) to shed light on the perspective of end-users, including a bandwidth of expected variation between costs and benefits for different stakeholders. This project resulted in a large dataset and an interactive dashboard, which allows municipalities to gather insights of the costs and benefits in the perspective of the above-mentioned actors. The dashboard also allows for applying splits of the total population, providing detailed cost-benefit information for varying house types, energy performance, ownership types and energy behaviours (Tigchelaar, et al., 2021).

RELEVANCE FOR EUROPEAN POLICY MAKERS

The current paper provides an overview of the approach, results and recommendations of the project that aimed to map the end-user costs and benefits associated with various energy transition scenarios for the built environment in the Netherlands. Since the detailing of local energy transition plans are – relative to Europe as a whole – in a more developed state in the Netherlands, we aim to provide with this paper a use-case that may serve as model for policy makers in Europe. Thereby, we hope the results and lessons learned from this project may provide useful insights to policy making in other European nations, that have yet to develop detailed energy transition plans for their respective housing sectors.

Methodology

For the Startanalyse, PBL has developed four main energy strategies providing an alternative to heating homes with natural gas[1]; an individual heat pump (S1), district heating with medium (S2) or low temperature heat (S3) and using biogas in a conventional condensing boiler or hybrid heat pump (S4). These strategies can be further divided in variants based on energy sources and insulation requirements, see Table 1. Variants require a different level of insulation. PBL has defined a special label considering only insulation measures and excluding installation measures: the building envelope (BE) label. For some variants, label D+ is sufficient for implementation of the space heating installation, for others a B+ label is a minimal requirement. B+ level means the entire building envelope is well insulated. For D+ most of the envelope, but not all has to be well insulated.

For each variant the changes in energy use (natural gas, biogas, electricity and heat) and investment costs (for insulation and installations) have been calculated by PBL for every dwelling in the Netherlands relative to the business-as-usual situation where houses continue to use natural gas (ECW, 2022). TNO aggregated these data to housing categories containing: five dwelling types, seven energy performance levels (energy labels), three forms of ownership (social rent, private rent and homeownership) and three levels of energy behaviour (a low, medium and high consumption profile). We also differentiated the costs between homeowners, tenants, landlords and the national government and added financial consequences of investments to reflect their actual costs and benefits.

COSTS AND BENEFITS

The costs of a variant are dependent on the type of stakeholder. Homeowners and landlords, for instance, have costs for maintenance and management of the building as well as the costs for the investments in energy saving measures (minus possible subsidies). As we assume in this study that all investments are financed by a loan or mortgage, these investment costs are translated into financing expenses such as instalment and interest. The costs for replacing the condensing boiler at the end of its lifetime have been subtracted from these investment costs, as these former costs would have been incurred in any case.

A tenant, on the other hand, could experience an increase in the rental price. This increase depends on the type of landlord, private or public, and the methodology used to calculate the increase. The government, finally, has expenses related to subsidies, allowances and mortgage interest reduction, which can increase depending on the measures taken.

A stakeholder can also experience benefits. When decreasing energy consumption, homeowners and tenants save on energy

1. Heating houses by burning natural gas in a condensing boiler is currently standard in the Netherlands.

Table 1. Strategies and variants of PBLs Startanalyse.

Code	Space heating alternatives	Variant code[2]	Space heating installation	Insulation level *)
S1	Individual electrical heat pump	S1a	Air-water heat pump	B+
		S1b	Borehole heat pump	B+
S2	District heating (medium temperature)	S2a	MT waste heat	B+
		S2b	MT geothermal energy	B+
		S2d	MT waste heat	D+
		S2e	MT geothermal energy	D+
S3	District heating (low temperature)	S3a	LT heat source, supplied at 30 °C	B+
		S3b	LT heat source, supplied at 70 °C	B+
		S3d	ATES, supplied at 50 °C	B+
		S3e	SWH+ATES, supplied at 70 °C	B+
		S3f	LT heat source, supplied at 70 °C	D+
		S3h	SWH+ATES, supplied at 70 °C	D+
S4	Individual central heating fuelled by Biogas[3]	S4a	Hybrid heat pump	B+
		S4b	Condensing boiler	B+
		S4c	Hybrid heat pump	D+
		S4d	Condensing boiler	D+

**) B+ = Entire building envelop well insulated; D+ Parts of building envelop insulated*

costs. Landlords will receive a higher rental price and in turn, tenants can get a higher rent supplement from the government. Because of a higher mortgage, homeowners will benefit from a higher mortgage interest reduction. The balance between the costs and benefits for each stakeholder determines the end-user costs. In our 2030 scenario, we assumed a reduction in the initial costs of energy efficiency measures, an increase in energy prices and a tax shift from electricity use to natural gas use.

All data used in these analyses can be found in the Dashboard itself which can be downloaded at Expertise Centrum Warmte (ECW, 2022). More detailed information on the methodology used can be found in a technical report (Tigchelaar, et al., 2021).

Results

In this section we discuss the main results of our data analysis. First, we will discuss the difference in investment costs and energy saving per strategy. Secondly, we will discuss the annual net costs of different strategies from an end-user perspective. Thirdly, we will look at the difference in subsidy available per strategy and we finish with an overview on the most efficient way to decarbonize the Dutch privately owned residential building stock.

Although all figures presented are calculated in detail and the authors put a lot of effort in obtaining the best information available, there is a lot of uncertainty in the costs and benefits of decarbonization strategies. In our dashboard and background studies we included a sensitivity analysis and put ranges on the figures presented. For sake of readability, in this paper we only present median values. However, it should still be noted that outcomes are not predictions and are uncertain.

INVESTMENT COSTS AND ANNUAL ENERGY SAVINGS PER STRATEGY

The investments to decarbonize the Dutch housing stock vary between different strategies. Table 2[4] shows that All-electric strategies and connecting to low temperature district heating are the most expensive, without subsidy. These strategies depend on expensive installations and require a high degree of insulation. Connecting to high-temperature district heating is cheaper. Investments in social housing are generally lower than in owner-occupied housing, because on average these dwellings are 10–20 % smaller in the Netherlands. Privately rented housing is somewhere in between. Due to the assumed cost reduction, the investment costs in 2030 will be lower than they were in 2020.

Investments in natural gas-free renovations are partly offset by savings on energy bills. Table 3 shows the weighted average change in annual energy costs per strategy by ownership. The table shows that strategies with fully electric and hybrid heat pumps deliver significant savings on energy bills. District heating strategies do not lead to major cost savings and in many cases to an increase in energy costs. This is due to Dutch legislation in which tariffs for district heating are based on natural gas tariffs. A switch to district heating will therefore not lead to lower costs. Legislation to base tariffs on the actual costs of heat production and distribution is in development but has not yet been approved in parliament. Such a policy could lead to more attractive cost for district heating in some neighbourhoods. When the table shows negative figures, these are the result of insulation measures that lead to a lower heat demand after renovation.

2. S2c, S3c and S3g are not included. They differ only slightly from S2b, S3b and S3f and have the same costs and benefits.

3. The availabilty of biogas is uncertain.

4. Results are weigthed averages in which different dwelling types and energy label categories are aggregated.

Table 2. Weighted average investment costs (excluding subsidies) per dwelling per strategy by ownership (€ x 1000).

Strategy and variant		2020 owner-occupied	2020 social rent	2020 private rent	2030 owner-occupied	2030 social rent	2030 private rent
S1 Individual electrical heat pump	a	21,9	18,1	21,8	19,1	15,7	19,0
	b	27,7	23,0	26,6	23,8	19,7	23,0
S2 District heating (medium temperature)	a	19,1	16,1	19,8	18,1	15,2	18,6
	b	19,1	16,1	19,8	18,1	15,2	18,6
	d	10,1	8,5	10,3	9,9	8,3	10,0
	e	10,1	8,5	10,3	9,9	8,3	10,0
S3 District heating (low temperature)	a	21,5	17,9	21,6	20,4	17,0	20,4
	b	19,1	16,1	19,8	18,1	15,2	18,6
	d	21,5	17,9	21,6	20,4	17,0	20,4
	e	19,1	16,1	19,8	18,1	15,2	18,6
	f	10,1	8,5	10,3	9,9	8,3	10,0
	h	10,1	8,5	10,3	9,9	8,3	10,0
S4 Biogas	a	14,2	12,3	16,0	12,2	10,4	13,9
	b	10,5	8,8	12,6	9,5	8,0	11,5
	c	5,1	4,7	6,5	3,9	3,5	5,1
	d	1,4	1,2	3,0	1,3	1,1	2,7

Table 3. Weighted average change in annual energy costs per dwelling per strategy by ownership, compared to the present situation in which the house is heated by individual natural gas boilers (€/ year).

Strategy and variant		2020 owner-occupied	2020 social rent	2020 commercial rent	2030 owner-occupied	2030 social rent	2030 commercial rent
S1 Individual electrical heat pump	a	-615	-505	-579	-1.049	-841	-949
	b	-678	-551	-628	-1.108	-885	-996
S2 District heating (medium temperature)	a	139	-73	87	42	-103	-19
	b	139	-73	87	42	-103	-19
	d	200	-18	176	127	-28	101
	e	200	-18	176	127	-28	101
S3 District heating (low temperature)	a	139	-73	87	42	-103	-19
	b	139	-73	87	42	-103	-19
	d	139	-73	87	42	-103	-19
	e	139	-73	87	42	-103	-19
	f	200	-18	176	127	-28	101
	h	200	-18	176	127	-28	101
S4 Biogas	a	-166	-120	-183	-379	-266	-360
	b	-54	-43	-97	-78	-62	-132
	c	-126	-82	-121	-340	-230	-301
	d	-7	-2	-23	-11	-5	-31

Apart from savings on energy, there are other minor changes in cost, like:

- Changes in maintenance costs
- Changes in tax returns
- Changes in rent allowance.

These changes in costs are not presented in this paper, but details are available in the Dashboard itself which can be found on the website of Expertise Centrum Warmte (ECW, 2022).

ANNUAL NET COSTS OF DIFFERENT STRATEGIES FROM AN END-USER PERSPECTIVE

All costs and benefits discussed in the previous section can be expressed in annual form. For example, investments can be converted into financial costs by calculating interest and amortization on a loan. For tenants, these investments can be translated into a rent increase. When annual costs and annual benefits are subtracted from each other, this results in so-called end-user costs. In this section we discuss these end-user costs per strategy, starting with the owner-occupied sector, followed by the social rental sector.

End-user costs for owner-occupied sector in 2020

For owner-occupants we calculated end user costs for types of financing. A situation in which investments are financed with a normal mortgage (maturity of the loan is 30 years for insulation and 15 years for installations. Interest rate is 1.7 percent) and one in which a government backed 'soft-loan' (maturity of the loan is 20 years and interest rate is 2.0 percent) is used. On average these annual costs are between €600.-– and € 1,200. – when a mortgage is used for financing and €800.– and €1,400. – when a soft loan is used. Only the biogas-based strategies result in much lower net costs.

Table 4 shows the theoretical situation in which the entire owner-occupied sector was decarbonized just with each specific strategy. This amount has been calculated by multiplying the costs and benefits per housing category by the number of

Table 4. End-user costs for private owners, reference year 2020. The costs per dwelling represent the average end-user costs over all dwelling typologies, weighted to the total count of dwellings per type. For the addition of these privately owned dwellings to sector totals in the table below, presented average costs per dwelling are multiplied by the total amount of dwellings in the privately owned sector.

Strategy and variant		Per dwelling (€/year)		Total privately owned dwellings (bln. €/year)	
		Mortgage	Soft loan	Mortgage	Soft loan
S1 Individual electrical heat pump	a	694	832	3,1	3,7
	b	1048	1185	4,6	5,3
S2 District heating (medium temperature)	a	1003	1216	4,4	5,4
	b	1003	1216	4,4	5,4
	d	643	740	2,9	3,3
	e	643	740	2,9	3,3
S3 District heating (low temperature)	a	1173	1386	5,2	6,1
	b	1003	1216	4,4	5,4
	d	1173	1385	5,2	6,1
	e	1003	1216	4,4	5,4
	f	643	740	2,9	3,3
	h	643	740	2,9	3,3
S4 Biogas	a	626	765	2,8	3,4
	b	420	560	1,9	2,5
	c	246	268	1,1	1,2
	d	45	68	0,2	0,3

Table 5. End-user costs for private owners, reference year 2030. The costs per dwelling represent the average end-user costs over all dwelling typologies, weighted to the total count of dwellings per type. For the addition of these privately owned dwellings to sector totals in the table below, presented average costs per dwelling are multiplied by the total amount of dwellings in the privately owned sector.

Strategy and variant		Per dwelling (€/year)		Total privately owned dwellings (bln. €/year)	
		Mortgage	Soft loan	Mortgage	Soft loan
S1 Individual electrical heat pump	a	93	218	0,4	1,0
	b	371	496	1,6	2,2
S2 District heating (medium temperature)	a	866	1067	3,8	4,7
	b	866	1067	3,8	4,7
	d	569	663	2,5	2,9
	e	569	663	2,5	2,9
S3 District heating (low temperature)	a	1026	1226	4,5	5,4
	b	866	1067	3,8	4,7
	d	1026	1226	4,5	5,4
	e	866	1067	3,8	4,7
	f	569	663	2,5	2,9
	h	569	663	2,5	2,9
S4 Biogas	a	297	424	1,3	1,9
	b	354	480	1,6	2,1
	c	-47	-26	-0,2	-0,1
	d	38	58	0,2	0,3

homes in the Netherlands in this category in 2019. Of course, this is a theoretical situation that does not consider the availability of energy sources. For options such as biogas or heat sources, there is not enough supply to provide for all owner-occupied homes. The planning of the strategy can also be limited, for example because there is insufficient space in the subsurface for a heat network. In practice, not all homes are made more sustainable at once and with one and the same variant.

End-user costs for private homeowners in 2030

Table 5 shows the end-user costs for the target year 2030. These costs are lower than in 2020, especially for Strategy 1 and 4a and 4c, where a large decrease of 20 percent in the costs of heat pumps is assumed. Also, gas prices are assumed to rise with 40 percent. The expected cost reduction for insulation is about 10 percent and therefore less than for installations. Therefore, strategies that insulate to a higher degree remain relatively more expensive than options that insulate to a lesser degree.

End-user costs in social housing

There are two actors in the rental sector: the tenant and the landlord. The tenant's end-user costs are determined by the savings on the energy bill on the one hand and the extra net rental costs on the other. For landlords the financing of additional investments leads to additional costs, and this is partly mitigated by additional income from increased rent. The extent to which the rent can be increased is therefore very decisive for the level of end-user costs for both the tenant and the landlord. The legal preconditions and agreements between landlords and tenants partly determine the rent increase.

Two methods of rent increase are included in the End User Costs Dashboard:

- **The rent tribunal method** is based on the principle that landlords can only pass-through costs they made for home improvements. A guideline dictates which terms should be used for calculating annual costs. Rent increase may not surpass these and tenants can ask a commission to enforce these rules to landlords. Landlords may not exceed rents set by this method, but it is possible for them to set lower rent increases. Rent increase in the Netherlands is not limited in years, so landlord will have additional benefits even after loans are repaid.
- **The Social Rental Agreement** is a voluntary agreement between Aedes, the representative body for social housing associations, and the Woonbond, an interest group for tenants. This agreement contains guidelines for rent increase after energy efficiency measures are installed (Aedes & Woonbond, 2018). The rent can be increased much less in this method than in the rent tribunal method, but the Social Rental Agreement is voluntary.
- The additional rent landlords can ask differs a lot between the two methods. If landlords comply with the Social Rental Agreement additional rent benefits do not outweigh additional investments in energy efficiency for them. Tenants will profit from lower overall housing cost though. If the rent tribunal method is used, tenants will end up with higher overall housing costs.

Costs for the social landlord

Table 6 shows the end-user costs for social landlords per home and as a sum for all social rental homes in the Netherlands. In none of the strategies are renovations beneficial for the landlord.

Table 6. End-user costs for landlords in the social sector, reference year 2020. The costs per dwelling represent the average end-user costs over all dwelling typologies, weighted to the total count of dwellings per type.

Strategy and variant		Per dwelling (€/year)		Total for complete social housing stock (bln. €/year)	
		Rent tribunal method	Social rental agreement	Rent tribunal method	Social rental agreement
S1 Individual electrical heat pump	a	250	1043	250	1043
	b	289	1379	289	1379
S2 District heating (medium temperature)	a	371	742	371	742
	b	371	742	371	742
	d	235	315	235	315
	e	235	315	235	315
S3 District heating (low temperature)	a	391	892	391	892
	b	371	742	371	742
	d	391	892	391	892
	e	371	742	371	742
	f	235	315	235	315
	h	235	315	235	315
S4 Biogas	a	224	625	224	625
	b	149	434	149	434
	c	88	234	88	234
	d	12	51	12	51

Table 7. End-user costs for tenants in the social sector, reference year 2020. The costs per dwelling represent the average end-user costs over all dwelling typologies, weighted to the total count of dwellings per type.

Strategy and variant		Per dwelling (€/year)		Total for complete social housing stock (bln. €/year)	
		Rent tribunal method	Social rental agreement	Rent tribunal method	Social rental agreement
S1 Individual electrical heat pump	a	1406	-375	2,7	-0,7
	b	328	-422	0,6	-0,8
S2 District heating (medium temperature)	a	315	89	0,6	0,2
	b	315	89	0,6	0,2
	d	172	123	0,3	0,2
	e	172	123	0,3	0,2
S3 District heating (low temperature)	a	389	89	0,8	0,2
	b	315	89	0,6	0,2
	d	389	89	0,8	0,2
	e	315	89	0,6	0,2
	f	172	123	0,3	0,2
	h	172	123	0,3	0,2
S4 Biogas	a	250	-31	0,5	-0,1
	b	189	11	0,4	0,0
	c	89	-34	0,2	-0,1
	d	31	5	0,1	0,0

Costs for the social tenant

For the tenant, rent increases in accordance with the Social Rental Agreement are much more favourable than a rent increase according to the11 rent tribunal method. With the strategies with heat pumps, tenant overall housing costs improve on average. This is not the case with heat networks. The maximum rent increase for sustainability in the Social Rental Agreement has been set in such a way that an average resident earns back the rent increase with the savings on the gas bill. In the end-user costs Dashboard, the variant with heat networks is based on the maximum rates for the variable rate based on legislation and tenants must pay a higher standing charge than for gas. The savings on energy bills are therefore smaller for tenants than with a gas-fired or heat pump variant and do not outweigh the rent increase.

AVAILABLE SUBSIDIES FOR DIFFERENT STRATEGIES

Table 8 shows the effect of subsidies that are now available for different strategies for owner-occupiers. Landlords can also apply for subsidies, with similar effects, but because lack of space these are not shown in this paper. Although subsidies for district heating strategies are comparable to other strategies, they cover a larger part of the total investment required. Connecting to district heating requires few investments in the homes themselves, but still a specific subsidy is available for making such connections. Investment subsidies for biogas strategies are relatively low. But the production of biogas itself requires a large amount of subsidy. These subsidies are not included in this table but do result in lower prices for biogas.

MOST EFFICIENT WAY TO DECARBONIZE THE DUTCH PRIVATELY OWNED RESIDENTIAL BUILDING STOCK

Overview of most cost-effective strategies in 2020

Table 9 presents the most cost-effective strategies with which specific dwelling types can be decarbonized with by owner-occupants. The table is sorted from lowest to highest net costs. The table also includes the total annual net cost for the sector. Since biogas is scarce and not available for most of the Dutch housing stock, these strategies were excluded from this table. For houses with an A or B score on the energy performance certificates, all-electric options are the most economical. For other houses, district heating can be the most economical option.

The table shows that none of the dwelling types can be decarbonized with net-zero costs. If you want to prevent owner-occupants incurring additional costs after refurbishing, you can grant investment subsidies. Table 9 shows the total amount needed in the theoretical case in which all dwellings must be refurbished with net zero costs for the owner-occupants in 2020. In this case almost €55 billion is needed to phase out natural gas in all owner-occupied dwellings.

Overview of most cost-effective strategies in 2030

In our 2030 scenario, we assumed a reduction in the initial costs of energy efficiency measures, an increase in energy prices and a tax shift from electricity use to natural gas use. Due to these assumed changes, phasing out natural gas will become much more cost-effective. With these changes, all-electric options are becoming the most economical strategy for almost all dwelling types. The total amount of subsidy needed for cost-neutral renovations will be reduced to €18.3 million homes need no subsidy to renovate cost-effectively.

Conclusions and recommendations

This paper describes the end-user costs for decarbonization for stakeholders such as homeowners, tenants, landlords and the national government. These actual 'end-user' costs are defined as balance of costs and benefits of the required initial investments, running costs, financial benefits and energetic benefits (expressed in monetary value).In this paragraph we will discuss our main conclusions and policy recommendation. Herein, we paid specific attention to the cost-effectiveness of different

Table 8. Average investment costs with and without subsidy and the average absolute and relative effect of the subsidy per variant for owner-occupiers in 2020 (in €1000/dwelling).

Strategy and variant		Weighted average investment (1000€/dwelling)	Weighted average investment after subsidy (1000€/dwelling)	Absolute effect subsidy (1000€/dwelling)	Relative effect subsidy (%)
S1 Individual electrical heat pump	a	21,9	18,2	-3,7	-17%
	b	27,7	22,9	-4,9	-18%
S2 District heating (medium temperature)	a	19,2	14,1	-5,0	-25%
	b	19,2	14,1	-5,0	-25%
	d	10,1	6,5	-3,6	-33%
	e	10,1	6,5	-3,6	-33%
S3 District heating (low temperature)	a	21,5	16,5	-5,0	-27%
	b	19,2	14,1	-5,0	-30%
	d	21,5	16,5	-5,0	-27%
	e	19,2	14,1	-5,0	-30%
	f	10,1	6,5	-3,6	-41%
	h	10,1	6,5	-3,6	-41%
S4 Biogas	a	14,2	11,4	-2,9	-20%
	b	10,5	8,8	-1,7	-17%
	c	5,4	3,7	-1,5	-26%
	d	1,4	1,1	-0,3	-20%

Table 9. Overview of most cost-effective strategies per dwelling/ energy label combination to phase out natural gas in 2020 excluding biogas strategies and subsidy needed to achieve net zero costs for the entire stock of privately owned homes.

Dwelling type	Energy label	Most cost-effective strategy	Net cost per dwelling (€/ year)	Number of dwellings (x1000)	Total net costs (mln. €/ year)	Subsidy needed (mln. €)
detached	A	s1a	112	206	23	540
multi-family	A	s1a	215	112	24	560
detached	B	s1a	219	158	35	809
multi-family	B	s1a	238	106	25	590
semi-detached	A	s1a	250	140	35	818
semi-detached	B	s1a	297	126	38	877
corner house	A	s1a	303	133	40	944
corner house	B	s1a	340	120	41	955
terraced house	A	s1a	353	228	80	1,878
terraced house	B	s1a	379	231	88	2,048
multi-family	D	s2d	528	122	64	1,500
multi-family	C	s2d	529	184	97	2,271
multi-family	E	s2d	605	49	30	692
semi-detached	D	s2d	621	142	88	2,064
terraced house	C	s3f	622	448	278	6,499
semi-detached	C	s2d	622	216	134	3,140
corner house	C	s3f	624	206	129	3,004
corner house	D	s3f	630	136	85	1,996
terraced house	D	s3f	632	230	145	3,390
detached	C	s3h	643	263	169	3,948
semi-detached	E	s2d	650	57	37	871
detached	D	s3h	661	119	79	1,844
multi-family	F	s2d	686	49	34	787
terraced house	E	s3f	687	98	67	1,573
corner house	E	s3f	705	55	39	900
corner house	F	s3f	728	46	33	779
detached	E	s3h	754	98	74	1,725
semi-detached	F	s2d	795	48	38	892
terraced house	F	s3f	808	56	46	1,063
multi-family	G	s2d	863	68	58	1,360
detached	F	s3h	867	78	68	1,586
terraced house	G	s3f	913	15	14	327
corner house	G	s1a	988	17	17	389
semi-detached	G	s2d	1,121	18	20	463
detached	G	s3h	1,499	55	82	1,910
TOTAL				**4433**	**2,355**	**54,990**

strategies and how these compare. Furthermore, we will reflect on the total investments and subsidies required to effectively phase out natural gas for heating of dwellings.

COST-EFFECTIVENESS OF DECARBONISATION STRATEGIES

Our analysis shows how much the phase-out of natural gas in Dutch households as primary heating source will cost for different actors. We looked at 14 different renovation strategies, including options with all-electric heat pumps, district heating and hybrid systems in which heat pumps are combined with biogas. We calculated costs and benefits for 315 reference situations based on different dwelling types and consumption profiles. For each of these we perceived costs and benefits from the perspective of a homeowner, a tenant and a landlord.

The findings of the current study show that in 2020 none of the 14 strategies were cost-effective for private homeowners in any of the 315 reference situations, meaning financial costs outweigh the monetary benefits due to energy savings in all circumstances. This is also true for rental homes. However, in that case the costs and benefits are split between landlords and tenants. The extent to which landlords (are allowed to) pass on their additional costs to their tenants after improving energy efficiency, by means of increasing rent, determines if either of them can profit from the renovation. But since the renovations are uneconomical to begin with, financial gains for a tenant will lead to losses for the landlord and vice versa.

In our 2030 scenario we assumed a reduction of initial costs on energy efficiency measures, an increase of energy prices and a tax shift from electricity use to natural gas use.[5] Because of these assumed changes, phasing out natural gas becomes more cost-effective. Over 3.2 million privately owned dwellings of the total of 4.5 million in the Netherlands can be renovated cost-effectively in this scenario.

In 4 of the 14 strategies biogas is used as an option to replace natural gas. Biogas is more expensive to produce than natural gas, even in the 2030 scenario. However, since producers of biogas are subsidized, the end-user will not have these direct additional costs included on their energy bill. Instead, cost are paid by all taxpayers. This makes biogas an attractive alternative from an end-user perspective. Especially in already

5. We did not include potential CO_2 pricing in our scenarios.

Table 10. Overview of most cost-effective strategies per dwelling/ energy label combination to phase out natural gas in 2030 excluding biogas strategies and subsidy needed to achieve net zero costs for the entire stock of privately owned dwellings.

Dwelling type	Energy label	Most cost-effective strategy	Net cost per dwelling (€/ year)	Number of dwellings (x1000)	Total net costs (mln. €/ year)	Subsidy needed (mln. €)
detached	A	s1a	-532	206	-110	-
detached	B	s1a	-452	158	-71	-
semi-detached	B	s1a	-275	126	-35	-
semi-detached	A	s1a	-275	140	-38	-
terraced house	B	s1a	-191	120	-23	-
terraced house	A	s1a	-178	133	-24	-
multi-family	A	s1a	-143	112	-16	-
multi-family	B	s1a	-137	106	-15	-
corner house	B	s1a	-109	231	-25	-
corner house	A	s1a	-98	228	-22	-
detached	C	s1a	-30	263	-8	-
detached	D	s1a	98	119	12	271
semi-detached	C	s1a	134	216	29	674
multi-family	C	s1a	168	184	31	720
multi-family	E	s1a	189	49	9	216
detached	E	s1a	204	98	20	466
terraced house	C	s1a	209	206	43	1422
multi-family	D	s1a	223	122	27	634
multi-family	F	s1a	267	49	13	306
terraced house	G	s1a	284	17	5	155
corner house	C	s1a	296	448	132	2184
terraced house	F	s1a	314	46	14	450
corner house	E	s1a	334	98	33	922
multi-family	G	s1a	382	68	26	606
detached	F	s1a	388	78	30	706
corner house	G	s1a	392	15	6	99
terraced house	E	s1a	403	55	22	430
corner house	D	s1a	403	230	93	2509
semi-detached	D	s1a	411	142	58	1362
corner house	F	s1a	419	56	23	411
terraced house	D	s1a	467	136	64	1281
semi-detached	G	s1a	473	18	9	199
semi-detached	F	s1a	506	48	24	567
semi-detached	E	s2d	541	57	31	720
detached	G	s1a	782	55	43	1004
TOTAL				**4433**	**411**	**18,315**

energy-efficient homes, the investment required for the undertaking of necessary measures to the dwelling itself are limited. Unfortunately, there are societal downsides to the utilisation of biogas. Firstly, biogas is produced from scarce source materials and financially expensive to produce. Secondly, without direct compensation, using biogas for dwelling heating leads to the emission of greenhouse gases, which contradicts the purpose underlying the energy transition. Thereby, the use of biogas should be limited to homes where alternatives are technically and financially challenging, like monumental buildings. If we exclude biogas from our analysis, 2 million instead of 3.2 million privately owned dwellings can be renovated cost-effectively.

Investments in insulation measures are not profitable in 2020, nor are they profitable in 2030, despite the assumed cost reduction. This makes it more expensive to renovate homes with an inferior Energy Performance Certificates (EPCs), where investments in insulation are more significant. The recast of the Energy Performance of Buildings Directive (EPBD) aims to renovate the worst performing buildings first. But from a pure cost-effectiveness optimization perspective, it is therefore recommended to start refurbishing A and B labelled homes, in order to meet the 2030 national target of refurbishing 1.5 million homes. However, investments in energy efficiency serve multiple purposes, such as alleviating energy poverty and reducing the demand for scarce (renewable) energy sources. Also, the absolute reduction of CO_2-emissions will be smaller compared to a strategy aimed at less efficient homes. Consequently, a different prioritization than one from a pure financial standpoint may be desirable.

Under Dutch law, the tariffs per functional unit of heat provided for district heating are linked to those for natural gas. The intention was to prevent district heating customers from paying more than natural gas users in comparable homes. But because of this law, switching from natural gas to district heating does not result in savings on energy bills for end-users. In fact, the intended supplementary tax on natural gas will also lead to a higher energy bill for customers of district heating. The Dutch government is working on a legal adjustment whereby district heating rates are no longer linked to natural gas but are based on the actual costs of heat suppliers. We recommend that the Dutch government implement these changes quickly, to make district heating a viable and more cost-effective alternative to natural gas.

In contrast to district heating, heat pumps benefit from the intended tax shift from electricity to natural gas. As a result of this shift, the savings on the gas bill increase and the substitutional costs on electricity. Furthermore, we assumed further cost reduction for heat pumps in 2030, since learning effects are expected to be higher for this specific technique in the Netherlands. Hence, our analysis shows that strategies including heat pumps are more attractive in 2030 than alternatives without. This is especially true in dwellings where no additional investments in insulation are necessary.

TOTAL INVESTMENTS AND SUBSIDY NEEDED TO PHASE OUT NATURAL GAS IN DUTCH RESIDENTIAL BUILDINGS.

Phasing out natural gas in all Dutch owner-occupied homes will cost between 44 and 123 billion Euros until 2050, depending on the strategies chosen, if biogas strategies are not considered. Cost savings can reduce this to between €42 and 106 billion. But most costs can be offset by saving on energy bills. Selecting the most cost-effective strategies for each property type can significantly reduce annual net costs. Shifts in the energy tax from electricity to natural gas can also reduce costs. Taken together, the sum of unprofitable investments can be reduced to €18.3 billion for 4.5 million homes, or on average only about €4100 per home.

The Dashboard for end-user costs developed for the Dutch phase out of natural gas is an example of how detailed analyses can help to improve decision making and planning for large scale refurbishing plans in Europe.

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