How earthquakes shook up Dutch energy policy: an overview on who should do what, when and how to renovate 99 % of all Dutch houses in the next 30 years

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Abstract

The energy policy of the Netherlands has made a dramatic shift in the last years. The province of Groningen suffers from earthquakes, caused by decades of gas extraction. As a response, the National government reduced onshore gas extraction with over fifty percent already and decided it should be terminated completely before 2030. The biggest industrial gas consumers are forced to change to alternatives. But the most ambitious target of all is to completely replace the use of natural gas for renewable energy in residential and non-residential buildings in the next three decades, leading to zero emissions in 2050 in the built environment.

In 2015, in the Netherlands 87 percent of all houses are heated with individual gas fired central heating systems. Also 12 % was heated with gas fired collective heating systems. That means that all but one percent of all houses in the Netherlands will be affected by this shift in policy. On average a thousand houses should be transformed and renovated every day, many of them on a large scale, for the next thirty years.

Although almost 30 % of the Dutch housing stock is owned by housing associations, most houses have to be renovated by individual homeowners. Dutch houses have been made more energy efficient gradually in the last decades. Now policy must switch from supporting minor renovation to facilitate major renovations in order to replace natural gas for alternative renewable energy sources.

In this paper we will discuss the scale of the task ahead. The authors of the paper are involved in the ex-ante evaluation of the Dutch Climate agreement, to be signed in December 2018. This agreement will contain specific measures to facilitate the transition of the Dutch built environment. In this paper we will discuss the natural gas free concepts that are being discussed, the supporting policies as well as the costs and benefits both for society as a whole and for individual households.

Since it will be their houses that must be changed, individual homeowners and landlords are the key stakeholders in this process. All effort should be aimed at supporting them. In this paper we present the outcomes of a one year study that answers the wide-ranging question: Who should do what, when and how to renovate 99 % of all Dutch buildings in the next 30 years?

Introduction

71 YEARS OF GRONINGEN GAS EXTRACTION (1959–2030)

The history of natural gas production and consumption in the Netherlands

In 1959 a discovery was made in Dutch soil that would change the energy landscape of the Netherlands for decades to come. In Slochteren, in the province of Groningen, a natural gas field with the size of 2800 billion cubic meter (BCM), at the time the biggest known gas field in the world, was discovered (Barend J. Botter, 2009). The NAM, a cooperation of the Dutch government, Shell and Exon, quickly started with the exploitation of the field. Because of the anticipated competition with nuclear energy in the future, it was then decided to start production as soon as possible. Production started in 1963 only 4 years after the discovery. A vast gas transportation network was built to connect most of the dwellings and other buildings to the grid. In about a decade most Dutch households switched from coal and biomass based space heating to gas fired stoves and central heating systems. As Figure 1 shows, just fifteen years after this discovery, almost a hundred billion cubic meter of natural gas was produced in the Netherlands in total. Later this has been reduced to between 60 and 80 billion cubic meter annually eventually reaching below 50 billion cubic meter annually. Later the imports of gaseous natural gas increased. In most years about half of the total supply was consumed domestically. The remainder was exported. In the first years almost all gas came from Groningen. Later on a significant share of total gas production comes from the Groningen gas field with the remainder from the other onshore and offshore gas fields. In last two decades, natural gas production from the Groningen gas field still had a large share in total domestic production. In period 2000 to 2015 gas production from the Groningen gas field has been between 24 and 54 billion cubic meter annually (54 BCM in 2013) (Schoots et al., 2017). This shows the importance of this gas field in total production.

Earthquakes because of gas extraction

The extraction of gas from the Groningen gas field has led to soil subsidence later resulting in earthquakes. The first earthquake because of gas production was felt in December 1986 (KNMI website, 2019). The link between gas extraction and the severity of earthquakes has long been denied and downplayed by the NAM. In 2012 the frequency and heaviness of earthquakes increased dramatically (see also Figure 2[1]). From this moment on, the correlation between gas extraction and earthquakes was undeniable. Studies showed that the consequences for houses and buildings in Groningen could be much more severe than previously assumed. The earthquakes thus far, some with a force of more than 3 on the Richter scale, have caused severe damage to houses and buildings in Groningen. Several thousands of household have claimed compensation for repairs and many thousands of houses should be reinforced to be able to withstand future heavy earthquakes. The NAM and the Dutch government have set aside 18 billion euro to cover earthquake damage claims (RTL nieuws, 2018).

Phasing out gas extraction

Based on research it is very likely that the number of earthquakes directly correlates to the amount of gas extracted (KNMI, (2019). Based on this finding, the government has tightened the gas extraction limits since 2014. In 2018 it was decided to limit the gas production to 12 billion cubic metres before 2022 and completely end production in 2030. In 2018 the Dutch government announced extraction of natural gas from the Groningen gas field must be terminated completely by 2030 (Rijksoverheid, 2018a).

The government urged the 100 largest (industrial) users of natural gas to come up with phase-out-plans for the consumption of Groningen gas. During this phase-out the government will also increase capacity to import natural gas from abroad. One of the largest and most challenging action National policy targets announced is to phase out natural gas use in the built environment entirely before 2050. This is challenging since it requires a change that affects each household: it requires homeowners to buy different energy measures and appliances and often to make major renovations to their houses.

Merging climate policies and phasing out natural gas in the built environment

In 2018, the Minister of Housing stated that: "In 2050 all Dutch houses must be heated without natural gas" (Rijksoverheid, 2018b). This comprises a process of transforming 200 thousand dwellings each year from 2021 on with the aim to reduce CO_2 emissions to nearly zero in 2050.

The phase out of natural gas serves two policy goals:

1. Reduction of the demand for natural gas to decrease dependency of Groningen gas and increase security of supply (Rijksoverheid, 2018c).
2. Reduce CO_2 emissions of the built environment to nearly zero, to meet climate goals as defined in the Paris agreement

THE EXISTING HOUSING STOCK IN THE NETHERLANDS

Most Dutch households use natural gas for space heating, water heating and cooking. 83.9 % use gas fired condensing boilers, 3 % use other, less efficient individual gas fired boilers and 7 % is connected to gas fired collective heating in apartment blocks. That leaves only a bit more than 6 % of dwellings that is heated with electric heat pumps or district heating. To make things worse; the heat delivered via district heating to 4.5 % of Dutch dwellings is also for more than half based on gas fired CHP plants or gas fired boilers. Table 1 shows the development of gas connected dwellings. It shows that in 2015 only 1.5 % of dwellings were not directly or indirectly heated with natural gas.

In the annual National Energy Outlook, (Schoots, 2017) ECN made projections, based on simulation modelling of all energy related developments in the Netherlands including energy consumption in the built environment. The study projected that, despite implementing tighter building codes based on the Energy Performance of Buildings Directive (EPBD), the percentage of dwellings heated without natural gas will only slowly increase to 15,4 % in 2035. This growth will be mainly due to newly build dwellings 49 % of which is constructed without natural gas heating (RVO, 2018). Existing houses will most likely refrain from switching to other fuels for space heating based on the present policies.

The government changed its' building codes to forbid the use of natural gas heating systems in new buildings and houses. Since new construction covers only a small percentage of all buildings in the Netherlands this has limited effect on the share of dwellings connected to the grid. Without additional policies, renovations will not lead to a phase out of natural gas in existing dwellings. Table 2 shows that in a business as usual scenario, still 85 % of dwellings in 2035 will be heated with natural gas.

Uptake of renovation measures in houses

The number of taken isolation measures has been relatively stable over past last years (Table 3). In 2012 there was a national subsidy program for glass isolation. In 2013 we notice a decrease in taken isolation measures. This can be explained by

1. https://www.knmi.nl/over-het-knmi/nieuws/jaaroverzicht-aardbevingen-2018

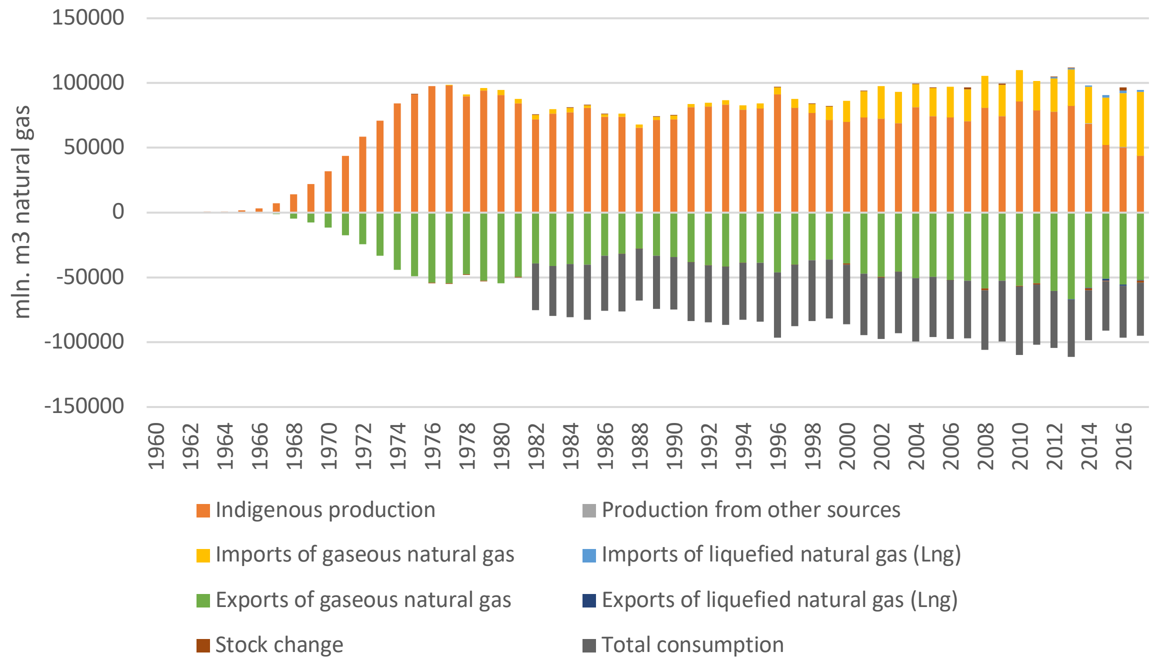

Figure 1. Gas production, import, export and consumption in the Netherlands 1960–2017 (source: CBS, 2018).

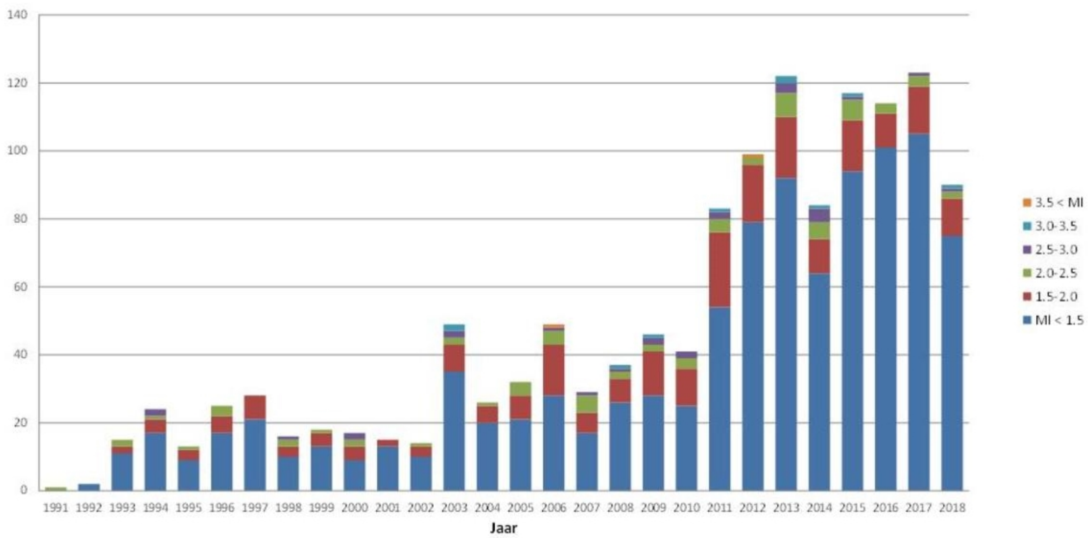

Figure 2. Number of yearly earthquakes in the Groningen field (source: KNMI).

Table 1. Number of dwellings with or without direct connection to gas grid (source: RVO, 2017)

[% of dwellings]	1995	2000	2006	2012	2015
Connected to gas grid	90.0 %	90.0 %	90.4 %	88.0 %	86.9 %
Individual central heating	73.1 %	78.7 %	82.2 %	84.7 %	83.9 %
Gas stove	16.9 %	11.3 %	8.2 %	3.3 %	3.0 %
Dwellings not connected to gas grid	10 %	10 %	9.6 %	12 %	13.1 %
Electric heat pump	0.0 %	0.0 %	0.2 %	0.5 %	1.5 %
Collective heating	7.4 %	7.3 %	6.3 %	7.4 %	7.1 %
District heating	2.6 %	2.7 %	3.2 %	4.0 %	4.5 %

Table 2. Number of dwellings with or without gas based space heating (source: Schoots, 2017).

	2015	2020	2025	2030	2035
Dwelling on natural gas including collective heating (x1000)	7,050	7,087	7,049	7,051	7,102
Percentage of total (%)	93.7 %	90.5 %	87.1 %	85.2 %	84.6 %
Percentage dwellings neither directly or indirectly heated with natural gas	6.3 %	9.5 %	12.9 %	14.8 %	15.4 %
Total number of dwellings (x1000)	7,522	7,828	8,091	8,279	8,399

Table 3. Number of isolation measures taken in houses (x1000). (Source: RVO, 2017 & 2018).

Isolation measures	2011	2012	2013	2014	2015	2016	Total 2011–2016	Average per year 2011–2016
Floor isolation	122	133	106	138	151	146	796	133
Roof isolation	156	197	124	155	148	148	929	155
Cavity wall isolation	116	120	96	131	133	160	756	126
Outdoor facade isolation	73	78	61	85	74	76	446	74
Glass isolation	292	363	215	267	265	262	1,665	277
Total isolation measures	759	891	603	776	771	791	4,591	765

Table 4. Number of installation measures taken in houses (x1000). Source (RVO, 2017 & 2018).

Installation	2011	2012	2013	2014	2015	2016	Total 2011–2016	Average per year 2011–2016
High efficiency gas fired boiler	376	383	303	349	320	332	2,063	344
Heat pumps	16	24	20	30	24	40	154	26
Solar boilers	17	17	16	24	15	15	104	17
Solar panels	24	103	151	154	170	161	763	127
Total installations	**433**	**528**	**490**	**557**	**530**	**548**	**3,085**	**514**

the end of the glass subsidy program and the crisis and its effects on the housing market. For installation measures (Table 4) we particularly notice an increase in solar panels. However, the number of heat pumps replacing highly efficient gas boilers still remains very low.

Table 3 and 4 show that single energy efficiency measures are installed in the Netherlands in a steady pace. Major renovations, needed to switch from natural gas to alternatives (see also the next paragraph), are not common though.

Based on the figures we conclude that more than 90 % of all existing dwellings in the Netherlands will have to implement a major renovation to phase out natural gas in the built environment. In the next paragraphs we will give an overview of the consequences of such a shift in policy.

Towards a housing stock without natural gas

In our study (Tigchelaar et al, 2019), sponsored by the ministry of economic affairs and climate, we gave an overview on who should do what in the future and how, to phase out natural gas for all existing Dutch dwellings before 2050. We analysed the technical concepts that can serve as an alternative for natural gas and the consequences it has on costs and benefits and other non-monetary effects for homeowners, grid operators, builders, municipalities et cetera. Since the dwellings, either privately owned or rented, are the place where all these consequences will come together, we took the perspective of the homeowners and landlords as the guiding principle for our analyses. What could trigger demand of homeowners for gas alternatives? What conditions are necessary in order to make them renovate their homes? What must change in the supply side to meet the demands of homeowners? And last but not least, what will this operation cost for homeowners and society as a whole?

RENOVATION CONCEPTS AS AN ALTERNATIVE FOR GAS HEATED HOUSES

We concluded earlier that more than 90 % of existing dwellings in the Netherlands have to be adjusted to some extent. There are different ideas on how to renovate dwellings in order to be able to disconnect them from the natural gas grid. In our study

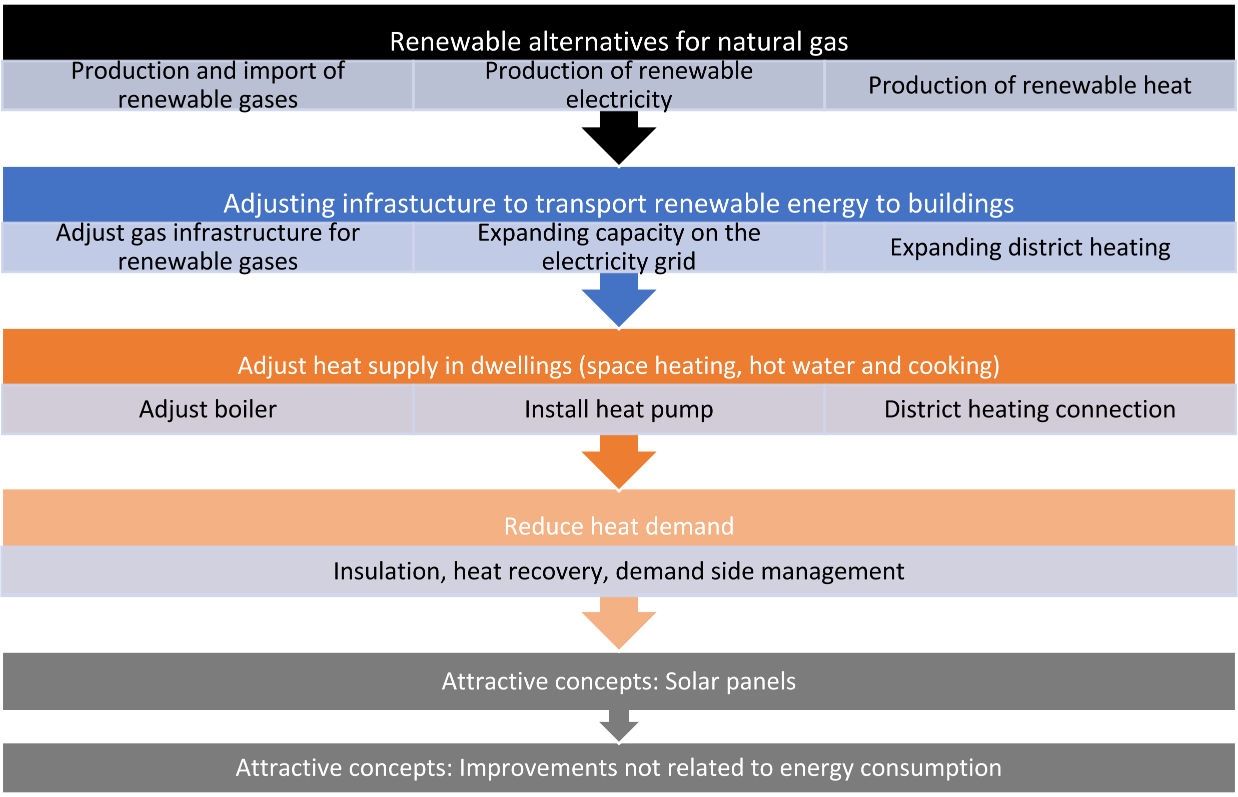

Figure 3. Building block for concepts without natural gas (source: Tigchelaar et al, 2019).

(Tigchelaar et. al, 2019)[2], we started to identify the six key building blocks necessary to all natural gas free renovation concepts.

Figure 3 shows six building blocks for natural gas free concepts for homeowners. When relevant the blocks are divided in three alternatives: A concept based on renewable gas that replaces natural gas in the grid, an all-electric concept in which the gas boiler is replaced by a heat pump and a concept in which the house is attached to a district heating network It is true for each concept that it only can function as an alternative for a house with a gas fired boiler if it contains at least the first four building blocks. Some of the blocks have to be implemented by the homeowner itself, others need to be implemented by the local governments and grid operators. As an example, the first building block is not something homeowners will be aware of at first , but this building block influences the other building blocks and they have consequences for homeowners. E.g. the selected infrastructure defines which heat supply solutions are suitable for homeowners.

The first building block is the supply of renewable energy to replace the natural gas used today. This can be either renewable gas based on biomass, renewable electricity for instance produced with wind farms or renewable heat for instance based on geothermal sources. Renewable energy in the Netherlands is mostly produced centrally on a large scale and the additional cost compared to fossil energy are subsidized by the government. This subsidy for Stimulation of Sustainable Energy Production (SDE+), is financed with a government fund filled with a levy on the energy bills of households and companies (RVO, 2019). This building block is often overlooked, but when municipalities will phase out natural gas in their neighbourhoods it is important that the supply of renewable energy is dealt with, otherwise the result could be that electricity or district heating is produced with natural gas and you have not phased out gas at all, but only transferred the problem from the residential to the energy sector.

The second building block is the change in infrastructure. Either the gas grid must be adapted to be able to transport renewable gases, the electricity grid must be reinforced to deal with the additional peak demands or a district heating system must be set up in the neighbourhood.

The third building block is the equipment for heating, hot water and cooking in the house that needs to be replaced. Alternatives are hybrid boilers that combine a boiler fired with renewable gas and a small electric heat pump, an all-electric system that uses a larger heat pump, or a set to tap heat from a district heating system.

The fourth block is the reduction of the heat demand by insulating the building. This is important because a more efficient house saves costs for the household. Next to that it reduces the demand for scarce renewable energy and government subsidies used for the production of the renewable energy. Insulation also reduces peak demands, so it helps to limit the investments in capacity of the grids. So although insulation is part of home improvement to be done by the homeowner, it is also beneficial for the government and grid operators.

Two other building blocks do not directly influence the use of natural gas, but are essential to make gas free concepts sufficiently attractive to homeowners. Installing solar panels helps

2. Our study gives an overview on who must do what, when and how to switch the Dutch housing stock to phase out natural gas in the Dutch existing housing stock before 2050.

to generate electricity but it does not reduce the demand for natural gas. Still it can be very attractive to include solar panels in concepts. Because of tax redemption systems in the Netherlands, solar panels have a payback time of about 7 years. In its lifetime of 25 years, they can generate quite a profit for the homeowner which can be used to cover unprofitable investments in for instance insulation.

The last block is also about making concept more attractive, in this case by utilizing non-energy related investments. Since large scale refurbishments could be necessary to phase out natural gas, it could be wise to combine them with other home improvements. Homeowners, not necessarily interested in energy related improvement, might be stimulated if the comfort and quality of their homes are improved as well. An option is to combine energy efficiency measures with renovations to adjust houses to better fit changes in the stage of life of dwellers.

The described building blocks are needed for a technically well executed natural gas free concept. The difficulty is that some of them need to be dealt with by the local government and grid operator, some have to be done by the homeowner himself. There is also a split incentives problem in which investment of one actor are beneficial for another or for society as a whole, but not per definition for the investor himself. Therefore coordination is needed. In the second half of this paper we will address how to organise this giant operation. We describe the current process of policy negations, the costs of this operation, and end with stimulating the demand of homeowners for natural gas free concepts.

CONSUMER CENTRED APPROACH TO STIMULATE UPTAKE OF GAS FREE CONCEPTS BY HOMEOWNERS

As can be seen in Table 2 , the uptake of renovations or gas free concepts is going slow. To increase the uptake several barriers need to be overcome. It would be impossible to implement gas free renovation at more than 7 million Dutch dwellings, by government decree. Only 15 % of Dutch citizen think that the national government should enforce the energy transition with strict policies and legislation, although qualitative results show that they do think it will be necessary to change their behaviour (SCP, 2016). Too much enforcement could lead to resistance of Dutch homeowners. But to leave it solely to voluntary choice of individuals on the other hand, would most likely not lead to the grand scale change needed. A middle way should be found. On one hand as free concepts should be made realistic, attractive, and on the other hand clarity regarding the deadline (when will the delivery of gas end), should be given, so a demand for it will grow.

Based on the CODEC model, developed by ECN part of TNO to analyse consumer decision making, the demand for gas-free-concepts can be determined by the three main determinants for consumer behaviour (Brunsting et al, 2018)

1. **Attention: are people engaged in decision making and considering gasless options?** The main barrier in this regard is that at the moment some homeowners may feel some urgency to phase out natural gas (Motivaction, 2016), but there is no immediate trigger to actually renovate the house. For example a central heating boiler will need to be replaced only once every 15 year. This means people will only consider heating alternatives every 15 year.) Policies should make a connection to moments when people are considering to buy a new boiler, move out or make major improvements to the house, since these are natural decision moments. At these times it should be ensured that households receive suitable offers (see "Enable" and "Intention"). Policies could also create new, and more urgent decision moments by communicating a deadline for when the delivery of gas will end.
2. **Enable: are people able to buy products and services/concepts?** The main barrier in this regard is that a lot of households may not be able to pay the investment costs of the gasless options, that depending on the type of dwelling can be 17 to 30 thousand Euro (VEH, 2018). About 50 % of homeowners have financial assets (not including their home) of less than 28 300 Euro (Ecorys, 2018), the average assets of Dutch households is 13,5 thousand Euro (CBS, 2016). In addition it is unclear for most people which measures are available and if they are suitable for their home (VEH, 2017). Alternatives to natural gas should be affordable and achievable in practice. Better and tailored information, one-stop-shop concepts and financial products can help to provide home owners with practical and financial support.
3. **Intention: do people want to buy products and services/concepts?** The main barrier in this regard is that most people are not willing to pay to make their home gas free (Motivaction, 2016). Alternatives to natural gas should become more attractive than standard gas fired options. They should perform better on cost and benefits, but also on status. Other advantages and ways of framing like improvement of comfort, can help to change preferences for homeowners. The last two building blocks described in section x are part of overcoming this barrier.

To create demand for natural gas free concepts, they should be treated more as products like any other product by policy makers. This means for example that they should be attractive to consumers, and should have a proper business case for the supply side. The 'supply side' consists of the national, regional and local government, grid operators, installers and construction workers, but also banks and advisors. Together they have to develop a natural gas free product that people find attractive, if possible more attractive than the current gas based default option. They should be aware of the 'customer journey', a term used in marketing, to identify the steps homeowners will go through and address the needs of consumers in the different steps. A cultural shift is needed with suppliers to focus more on the demands of homeowners and on collaboration with other actors. In 2018 all relevant stakeholders together draw up plans to make this shift. In December 2018 this has led to a concept Climate Agreement, which will be discussed on the next paragraph,

The National Climate Agreement

The Dutch government has set the goal to reduce CO_2 emissions with 49 % in 2030 compared to 1990 levels to comply with the Paris agreement goals. Phasing out natural gas in buildings is one of the key elements of government policy to achieve this. Instead of introducing policies top down by the government, the government asked Dutch NGO's, business representatives, local and regional governments and many more to draw up plans together that will achieve the target set. During 2018, the negotiations were held within five sector platforms: built environment, industry, agriculture and land use, mobility, and electricity.

In July a first draft version of the National Climate Agreement was presented (Proposal for key points of the Climate Agreement, 2018). Replacing natural gas in the built environment by renewable sources of heat is one of the key elements of the agreement. At the centre of the policy for the built environment is a district-oriented approach. In 2021 at the latest, municipalities will have to draw up a transition vision for heat together with residents and building owners. In these visions it should be made clear what the alternative energy infrastructure of that district will be and how this will be implemented locally. This provides a framework within which building owners, network operators, heat suppliers, municipal authorities and other parties can take investment decisions. To make implementation feasible, several other polices will be developed:

- Municipal authorities and stakeholders are supported by a guideline. It contains objective information based on transparent, validated factual data.
- Different actions are aimed at improving the affordability off gas alternatives. These include :
  - Increasing the tax on gas and lowering the tax on electricity will make insulation and sustainable heating more appealing. The shift will be structured in such a way that it eases the tax burden on households
  - Having a loan attached to the house rather than the occupant makes measures to improve sustainability more affordable
  - Innovation should lead to cost reduction of insulation measures and sustainable heat options. Construction companies, heat suppliers and installers are focusing on cost reductions of 15% to possibly 50% by 2030;
  - Additional subsidies will become available to cover unprofitable investments.
- Standards for housing should give clarity on the level of improvement needed for houses. The Government does not want to include these standards in the building code, but chooses for a voluntary approach, so for the moment these standards are just informative. Should this have insufficient effect, the standard could be made mandatory to a greater extent from 2030.
- The production of renewable heat is stimulated. At the moment 3 PJ of geothermal energy is produced in the Netherlands. There will be an action plan to increase this to 50 PJ geothermal energy by 2030 and more than 200 PJ by 2050. Water management companies expect to be able to supply 80 to 120 PJ of thermal heat from surface water.
- To have a swift start, parties are working towards achieving 75 % of total new housing without natural gas in the period from 1 July 2018 to the end of 2021. Housing associations aim to have transformed 102,500 existing houses in 2021 which then will not use natural gas anymore.

ASSESSED IMPACTS OF THE DRAFT NATIONAL CLIMATE AGREEMENT

The Netherlands Environmental Assessment Agency (PBL), which is the national institute for strategic policy analysis in the fields of the environment, nature and spatial planning, was asked to assess the effects of the draft plans for the National Climate Agreement. This draft plan did not contain concrete policy instruments, only a general approach. In the second half of 2018 the negotiations continued to develop these concrete instruments. A second draft that includes these instruments is published. PBL will assess this plan as well. Results of this assessment will be made public in March 2019. In this paragraph we will briefly discuss the results of the first assessment of the draft plans published in July 2018 (Klimaatakkoord, 2018). Some of the authors of this paper assisted PBL with the analysis done for the built environment platform (PBL, 2018).

The parties at the Climate agreement aim at a total of 1,5 million dwellings to be refurbished in 2030. Also the services sector should half its CO_2 emissions compared to 1990. The total package for the built environment should lead to 3,7 Mton of additional CO_2-reduction compared to the used reference scenario.

To achieve this CO_2-reduction, the number of refurbished houses should increase rapidly to 200 thousand annually. Table 5[3] shows how the 1,5 million dwellings are supposed to be divided over all-electric concepts, hybrid systems that combine (green) gas and renewable electricity and district heating. More than 40 percent of dwellings are assumed to be connected to a district heating system. To achieve the CO_2 effects it is necessary that enough renewable heat is generated to supply the district heating system. In the first years more social rent houses will be refurbished than privately owned houses. These houses are mostly in possession of housing corporations. In order to achieve the necessary costs reductions through innovation and scaling effects, a collective strategy was chosen in which these houses will be renovated first.

PBL Assessed the investment needed to accomplish a phase out of natural gas to be 18 to 23 billion Euro. The average national cost (excluding taxes and subsidies) will reach 300 to 600 million Euro annually between 2020 and 2030. This is based on a discount rate of 3 % and a recovery period of 15 years for installations and 40 years for insulation measures. Savings on energy cost are included in the figure. The main uncertainty is in the cost reduction that is aimed at 15–50 %. (PBL, 2018)

Cost and benefits for individual home owners

Total national costs range from 300 to 600 million annually, but how are these costs allocated? Who pays the bill? The answer is not as simple as dividing the total cost by the number of dwellings refurbished. Societal costs and benefits include all the costs and benefits for the society as a whole. Transfers within society are not taken into account. These transfers include taxes and subsidies. These are not part of societal costs because taxes paid by an end-user are gains for governments while for subsidies the contrary is true. When looking at the perspective of home-

3. Social rent houses are owned by housing associations and rental prices are regulated by law.

Table 5. Number of privately owned and social rented dwellings to be refurbished between 2019 and 2030 x1000 (source: PBL (2018).

	Privately owned houses			Social rent houses		
year	All-electric	Hybrid	District heating	All-electric	Hybrid	District heating
2019	*1.4*	*0.0*	*1.4*	2.5	5.0	10.0
2020	*2.8*	*0.0*	*2.8*	5.0	10.0	15.0
2021	*4.8*	*0.0*	*4.8*	10.0	20.0	25.0
2022	*7.7*	*15.4*	*12.6*	*7.7*	*15.4*	*27.8*
2023	*9.1*	*18.2*	*20.4*	*9.1*	*18.2*	*30.5*
2024	*10.5*	*21.0*	*28.2*	*10.5*	*21.0*	*33.3*
2025	*11.9*	*23.8*	*36.0*	*11.9*	*23.8*	*36.0*
2026	*15.0*	*30.1*	*36.0*	*15.0*	*30.1*	*36.0*
2027	*18.2*	*36.4*	*36.0*	*18.2*	*36.4*	*36.0*
2028	*21.3*	*42.7*	*36.0*	*21.3*	*42.7*	*36.0*
2029	*21.3*	*42.7*	*36.0*	*21.3*	*42.7*	*36.0*
2030	*21.3*	*42.7*	*36.0*	*21.3*	*42.7*	*36.0*
period 2019-30	145.3	272.7	286.2	153.9	307.7	357.5

Table 6. Cost per building block per alternative for natural gas in a reference dwelling [euro/dwelling/annually] (source: Tigchelaar et al., 2019).

	[euro/dwelling/ annually]	Reference natural gas option	renewable gas with hybrid system	All-electric	District heating
Supply of renewable energy	Investment (societal perspective)	316	724	331	749
	Balance of taxes and subsidies	485	113	558	149
	Investment (end-user perspective)	801	836	889	898
Adjusting infrastructure	Investment (societal perspective)	447	451	396	1,305
	Balance of taxes and subsidies	94	90	-71	-509
	Investment (end-user perspective)	541	541	325	796
Adjust the heat supply in a dwelling	Investment (societal perspective)	197	543	1,193	164
	Balance of taxes and subsidies	41	-48	38	34
	Investment (end-user perspective)	239	495	1,230	198
Reduce heat demand	Investment (societal perspective)	-	457	1,158	365
	Savings	-	-343	-371	-226
	Balance of taxes and subsidies	-	160	-382	32
	Investment (end-user perspective)	-	274	405	170
Solar panels	Investment (societal perspective)	-	270	672	270
	Saving (national)	-	-120	-299	-120
	Balance of taxes and subsidies	-	-271	-679	-271
	Investment (end-user perspective)	-	-121	-306	-121
Subtotal	Investment (societal perspective)	961	2,445	3,749	2,852
Subtotal	Balance of taxes and subsidies	621	-419	-1,206	-911
total	Investment (end-user perspective)	1,581	2,026	2,543	1,941

Table 7. First actions to be done before 2021 to start up the phase out of natural gas (source: Tigchelaar at al., 2019).

Who	What	When
National government together with knowledge institutes and suppliers	Develop a program for learning and cooperation	2019
National government	Provide clarity on the level of ambition and boundary conditions for phasing out natural gas.	before 2021
National government	Develop a view on the level of freedom of choice for home owners	before 2021
National government	Develop a view on who should pay what	before 2021
National government	Adjust legislation so municipalities, grid operators and other have the proper authorities to phase out natural gas in district and individual houses.	before 2021
Municipalities together with grid operators	Provide clarity tot home owners on the approach in their neighbourhood	before 2021

owners these transfers are obviously very important, because an increase in tax paid or subsidy received can make a huge different on the profitability of options.

Table 6 shows the annual costs for every building block per dwelling. It shows the societal costs, the cost for end-users and the balance of taxes and subsidies that explain the differences between the two. Costs indicated are for renovations of existing houses, in this case a reference dwelling (rowhouse) with 1.200 cubic meter annual gas consumption. In case of district heating the costs of a new network are given. One should note that costs per individual case may differ largely due to technology lock-ins of heating infrastructure. For instance, district heating becomes a much cheaper option if there is already a network present in the neighbourhood. With the assumptions made, hybrid heating systems are the cheapest alternative from a societal perspective, but still almost 1,500 Euro more expensive than the present gas based default options. When taxes and subsidies are taken into account, district heating becomes a more economical option. Hence, the results shown here indicate that implicitly, district heating is much more supported by the National government with combined 911 Euro of subsidies and tax redemptions than hybrid systems with only 419 Euro. All-electric options are supported with 1,206 Euro annually.

When tax and subsidy is incorporated, gas free alternatives are 500 to 1,000 Euro more expensive than the present gas based options. The figures in Table 3 are valid for the present situation. Changes in policy, for instance a change in taxation for gas and electricity, can influence this implicit support. The affordability of gas free alternatives can and must be improved, apart from changes in taxation, with innovation and new financial products.

Cost reduction is the only option that leads to increased affordability and also leads to lower national costs. By means of technical and system innovation, the costs of installations and insulation can be reduced. The Economic Institute for Buildings in the Netherlands (EIB) has identified the main forms of innovation and efficiency improvement needed to reduce the efficiency gap (i.e. the difference between investment costs and energy savings) (EIB, 2018). First of all, economies of scale can be achieved by not promoting home improvement per individual home but in larger projects. For instance tendering per street or neighbourhood or per dwelling type. A second efficiency gain can be achieved by industrialization. By prefabricating elements, renovating homes becomes cheaper, because expensive labour costs are replaced by cheaper capital costs. Industrialization can go hand in hand with robotization, which means that building elements are made precisely and there are fewer costs due to material loss and errors. When more renovations are based on standard concepts, costs can be further reduced by streamlining the process. The EIB estimates that through these innovations the costs can be reduced by a maximum of 15 % (EIB, 2018). It may occur that these cost reductions are partly offset by scarcity on the labour market, which means that labour costs in the construction sector rise faster than inflation.

Conclusion: Who should do what, when and how to phase out natural gas in the existing Dutch housing stock before 2050

Phasing out natural gas in houses has become a key element of Dutch energy policy. Since more than 90 % of dwellings in the Netherlands are directly or indirectly heated with natural gas, the task ahead is massive. We estimated that the additional costs in the coming decade are 300 to 600 million euros anually for society and between 500 to 1,000 Euro for individual households. The National Climate Agreement formulates many actions for stakeholders to be implemented in the years to come, but policy instruments have to be developed further.

In our study we drew conclusions, not all discussed in this paper, on the main issues and necessary steps to achieve a natural gas free Dutch housing stock in 2050:

1. There still is a lot of uncertainty with all stakeholders on who should do what to phase out natural gas in the Dutch housing stock before 2050.
2. A concept can only be assessed as an alternative for natural gas if the supply of renewable energy as well as the adjustments in infrastructure and the adjustments in dwellings are taken into account.
3. Stakeholders point out that independent knowledge is essential to make the right decisions.

4. It is not cost effective yet for society to phase out natural gas in the Dutch housing stock.
5. The cost effectiveness for end-users is to a large extend dependent on tariffs and subsidy set by the government
6. Consumer and consumer decision making should play a more central role in an approach to phase out gas.
7. Specific household characteristics should be taken into account, so that solutions can fit the demand of homeowners.
8. Information for homeowners should be made tailor-made
9. Natural gas free alternatives should be become attractive products that people want to buy.
10. A cultural shift is needed with suppliers to focus more on the demands of homeowners and on collaboration with other actors.
11. Learning in practice should be the focus for the first years.

Based on these conclusions we formulated who should do what, when and how to phase out natural gas in Dutch dwellings before 2050. Table 7 shows the first actions for the coming two years.

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