HOW RELEVANT IS THE NATURAL GAS DISTRIBUTION GRID IN COMPARISON TO THE ELECTRICITY DISTRIBUTION GRID AND HEATING GRIDS?

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Abstract

Current studies, investigating the developments of the energy system in light of the energy transition, predict a significant decline in natural gas demand until 2050. New competitors to the natural gas suppliers are entering the market to equip industry and buildings with electricity and heat, leading to challenges for the natural gas sector and especially for the distribution grid operators to remain competitive. To investigate these new challenges an interconnected approach reflecting the competition between natural gas, heat and electricity is necessary. Hence, this study focuses on sector coupling on a distribution grid level for the building sector by a combined analysis of a grid-based electricity, heat and natural gas supply. We aim at contributing to the following research question: How relevant is the natural gas distribution grid in comparison to the electricity distribution grid and heating grids in the building sector in 2050? To answer the question a techno-economic comparison of the three different grids is outlined, providing the general insight that the natural gas distribution grid could become the least relevant grid for supplying heat in buildings in 2050, but further analyses that are more detailed are necessary.

Introduction

Today, natural gas accounts for 23.8 % (2017) of primary energy demand in Germany (AGEB 2018), making it to the second most important primary energy carrier for Germany after mineral oils. However, not only as a primary energy carrier, also as a final energy carrier natural gas is used in nearly every energy demand sector. Households, commerce, trade and services (CTS) as well as industry are demanding for high shares of natural gas. Only in the transportation sector, cars fueled by natural gas could not yet accomplish high market shares in Germany. However, new competitors are entering the market, especially in the building sector (households, commerce, trade and services). For example, in well-insulated buildings, heat pumps are used to provide heat or heating grids are installed on a larger scale.

Different studies show the trend to significant demand decrease of natural gas until 2050 (dena 2018; BCG and prognos 2018; Öko-Institut and Fraunhofer ISI 2015; IEA 2019). A strong decrease in natural gas demand with the similar length of natural gas distribution grid will lead to a strong increase in specific operating costs (Wachsmuth et al. 2019) and consequently, the economic performance of the natural gas distribution grid becomes questionable. To investigate this development in more detail the following question arises: How relevant is the natural gas distribution grid in comparison to the electricity distribution grid and heating grids in the building sector of Germany in 2050?

After explaining the current situation and research question, the next chapter gives an insight into the method used to compare the natural gas distribution grid with the electricity distribution grid and heating grids. Afterwards, results are shown and a brief summary and conclusion together with a critical reflection is provided.

Methods

To investigate the new synergies and competition for the gas distribution grid, we first analyze the current state and future development of the natural gas final energy demand on a national level for Germany. Therefore, recent scenario results from different studies with high policy impact are compared. The studies selected are "Integrated energy system transformation" (dena 2018) conducted by dena - German Energy Agency, "Climate paths for Germany" (BCG and prognos 2018) by the Boston Consulting Group (BCG) and Prognos, as well as "Climate protection scenario 2050" (Öko-Institut and Fraunhofer ISI 2015) compiled by Öko-Institut and Fraunhofer ISI. All scenarios selected target a Greenhouse Gas (GHG) - reduction of 95% by 2050 compared to the level in 1990. Consequently, these are very ambitious GHG - reduction scenarios. In the (dena 2018) two scenarios are selected; one with a focus on electrification and the other one using a technology mix. From (BCG and Prognos 2018), the National Focus scenario is selected and (Öko-Institut and Fraunhofer ISI 2015) provides one climate protection scenario for an ambitious GHG-reduction. Comparing these scenarios gives further insight about the changing usage of natural gas and potential alternatives to natural gas based applications.

Further, a techno-economic comparison is conducted for the three different grids. Therefore, for the economical part, the grid length in km, withdrawal volume in TWh, grid expansion in 2017 and its investment, as well as the different cost components of the price for the energy carriers are investigated. To identify the grid expansion in 2017, the grid length of 2016 is subtracted from the grid length in 2017. For the investment per additional kilometer, the investment is divided by the length of expansion. The values of investment in 2017 are taken from the monitoring report of the federal grid agency (BNetzA) in Germany. Their definition of investment includes the new gross entries to property and the values of new property, plant and equipment rented and leased (BNetzA 2019).

Afterwards, the technical analysis focuses on the sector coupling technologies leading to the synergies and competition of the different grids. For this reason, the technologies are grouped according to their demand sector and their grid connection, as well as the grid level on which they are connected.

To provide more detailed insights, an exemplary comparison of three relevant sector coupling technologies in the buildings sector, namely a heat pump, a heating grid supplied by large heat pump and a gas boiler, is outlined. The comparison is performed by taking the perspective of the end user, living in an average single-family house with 100 m^2 (UBA 2019) and an average heat consumption of 172.3 kWh/m^2a (Walberg 2012). Apart from taking the capital expenditures (CAPEX) for purchasing the sector coupling technologies into account, the energy carrier prices have to be converted to the useful energy, e.g. heat, by dividing the price by the efficiency of the technology connected to the grid, leading to the operating expenditures (OPEX).

Based on the price per useful energy, different scenarios can be compared. The first scenario considers the current situation (status quo) with the base year 2017 and the situation in 2050. Secondly, the taxes and allocations are excluded and lastly, the influence of suppling synthetic methane imported from North Africa through the natural gas distribution grid to produce heat for building in a gas boiler is analyzed.

Results

The following chapter first provides the results gained by the scenario comparison. Thereafter, the insights provided by the techno-economic analysis are illustrated in detail and followed by the results from the exemplary comparison.

Development of the final energy demand in different studies

Based on the comparison of recent scenario results from different studies an insight into the current and future final energy demand is provided. Figure 1 shows the comparison of the natural gas final energy demand in TWh in 2015, 2030 and 2050. The demand is split into the three main application areas: building (blue), industry (orange) and transportation (grey). It can be observed that, out of four scenarios, three contain a significant decline in natural gas across all sectors. Only the technology mix scenario, provided by dena (2018), estimates a nearly constant development of the natural gas demand in total. However, a strong decrease in demand is visible as well in the building sector.

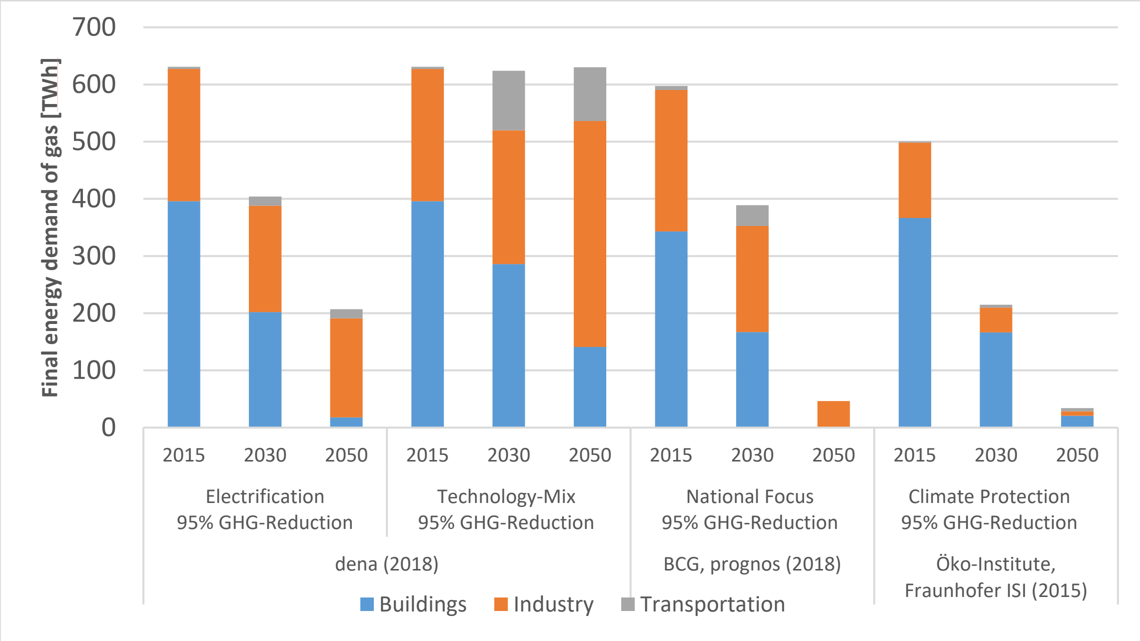

Figure 1: Development final energy demand of natural gas until 2050 (BCG and prognos 2018; dena 2018; Öko-Institut and Fraunhofer ISI 2015)

Taking a more detailed look into the alternatives to natural gas in the building sector, Figure 2 provides an overview of the demand development of district heating. Three out of four scenarios contain a decrease in district heating demand, whereas only the scenario of BCG and Prognos (2018) estimates a rather strong increase in district heating demand. Consequently, only in their scenario heat production in the building sector based on natural gas is partly compensated by district heating.

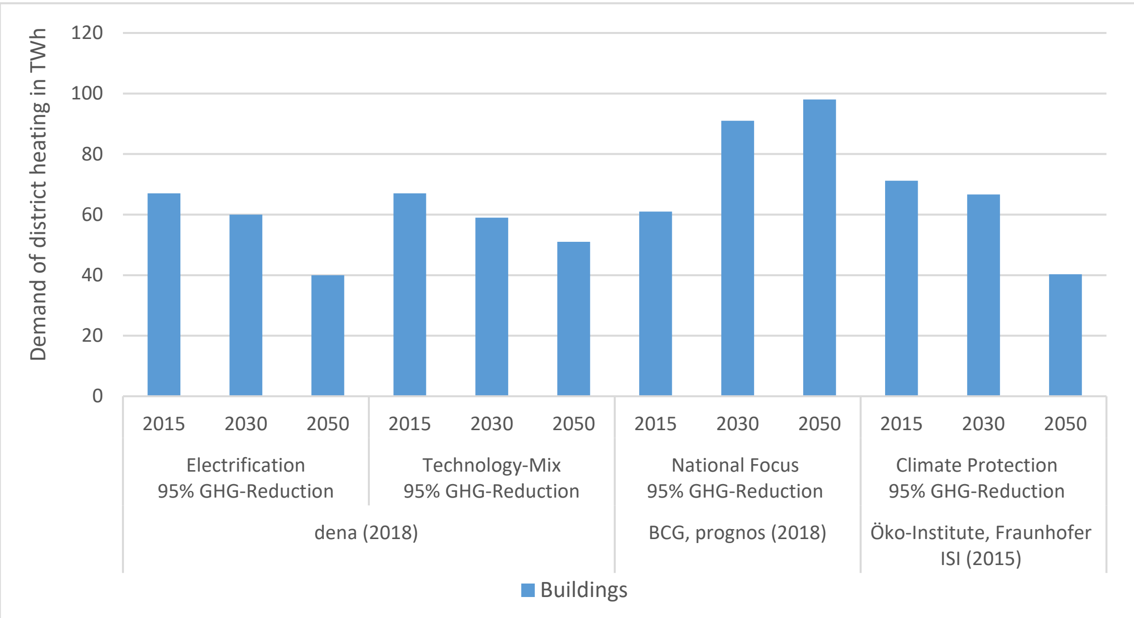

Figure 2: Development final energy demand of district heating until 2050 (BCG and prognos 2018; dena 2018; IEA 2019; Öko-Institut and Fraunhofer ISI 2015)

Figure 3 illustrates the development of electricity demand in the building sector (blue) and, if possible to differentiate, the electricity demand used to produce heat in buildings (orange). All scenarios comprise a slightly to strong increase in electricity demand and (BCG and Prognos 2018) as well as (Öko-Institut and Fraunhofer ISI 2015) contain a strong increase in heat production based on electricity.

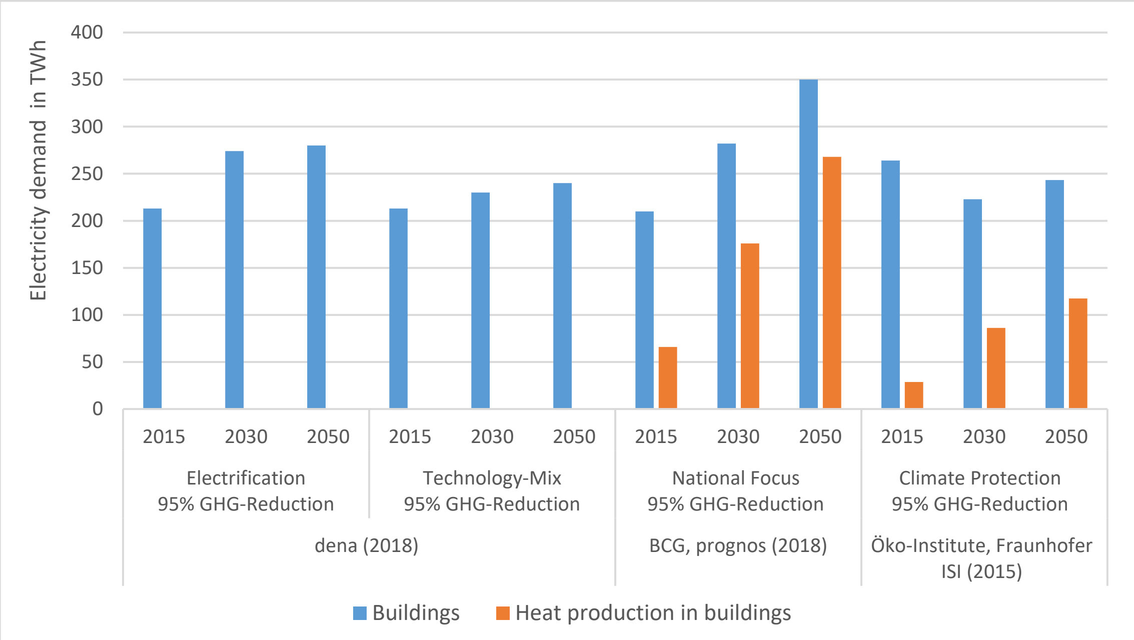

Figure 3: Development final energy demand of electricity until 2050 (BCG and prognos 2018; dena 2018; Öko-Institut and Fraunhofer ISI 2015)

Based on this comparison, we summarize that the studies estimate a shift from natural gas based heat production in buildings towards electricity based one. For district heating, the studies see different trends, with a tendency towards a decrease in demand, so that district heating seems to be of lesser relevance for heat supply of buildings in 2050.

Techno-economic analysis of the heating grid, gas and electricity distribution grids in Germany

In this subchapter, the results gained by the techno-economic analysis are outlined. Table 1 provides an overview of the length, withdrawal volume, grid expansion and investment in grid expansion of the three different grids in 2017 in Germany. The electricity distribution grid is with 1,807,895 km the longest grid and heating grids, being small local grids without a national wide connection, are the shortest with 21,610 km. Even though the electricity distribution grid is almost four times longer than the gas distribution grid, the latter distributes nearly double the amount of energy (withdrawal volume). Taking the grid expansion in 2017 into account, the expansion of the gas distribution grid is more than twice as big as the expansion of the electricity distribution grid, even though current studies estimate a decline in natural gas demand. Furthermore, the investment per kilometer of electricity distribution grid is significantly higher than the investment per kilometer of gas distribution grid. Consequently, expanding the electricity distribution grid appears to be far more expensive than expanding the gas distribution grid. A direct comparison between the investment in heating grids and the investment in gas and electricity distribution grid is not possible, because the heating grid investment includes the production of heat to supply the grid while the others do not.

Table 1: Overview of economical parameters of the three grids for Germany in 2017 (AGFW 2017, 2018; BNetzA 2017, 2019)

Parameter		**Gas distribution grid**	**Electricity distribution grid**	**Heating Grids**
Length (2017) in km		498,081	1,807,895	21,610
withdrawal volume (2017) in TWh	**Total**	752	445	75
	Industry/CTS	474	324	5
	Households	279	120	71
Grid expansion (2017) in km		652	320	90
Investment in Million €$_{2017}$/km		1.6	10.9	0.7

Comparing the different price components of the energy carriers in Figure 4, one may see that the market structures of natural gas and electricity are very similar; both markets are regulated and unbundled in light of the liberalization and both prices include network charges to gain a revenue for the grid distribution operator. In comparison to that, the price for heat from heating grids is split into two main components, base price and energy price. The base price includes investment in facilities, pipeline, transfer stations as well as labor costs for operation, maintenance and repair (AGFW 2018). Further, the energy price includes the energy demand of heat production and of the pump to transport the medium through the pipelines (AGFW 2018).

The amounts of taxes and allocations of the energy carrier price are illustrated in orange in Figure 4. These amounts are on a similar level for natural gas and heat from heating grids, whereas for the electricity price the amounts are considerable higher, leading to a significant higher price for electricity than for the other energy carriers.

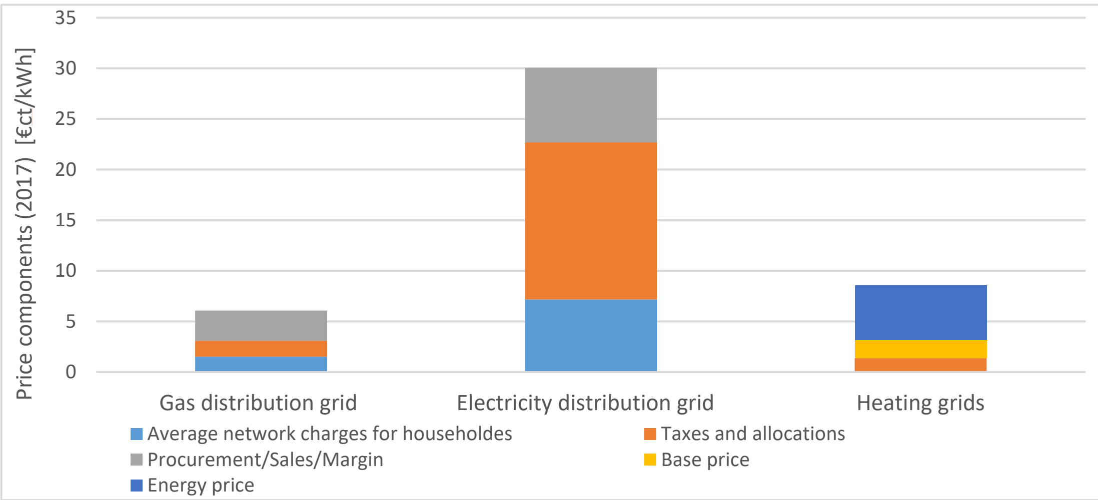

Figure 4: Components of the different energy carrier prices (AGFW 2018, 2017; BNetzA 2019)

For a more detailed comparison, the price of the different energy carriers needs to be converted to the same useful energy carrier, i.e. heat. Therefore, the price has to be divided by the efficiency of the conversion technology.

Before selecting exemplary conversion technologies, a more detailed technical view on the synergies and competition between heating grids, gas and electricity distribution grids is provided in Figure 5. The grey boxes on top illustrate the different demand sectors in which sector coupling takes place, whereas the grey boxes on the left side are the different grid-based energy carriers. In blue technologies that withdraw energy from the grid are shown and in green the technologies that feed-in energy into the grid.

Focusing on the building sector, gas boilers are connected to the natural gas distribution grid. The electricity distribution grid supplies electrical heater and heat pumps that compete with gas boilers to supply buildings with heat. A strong synergy is established between electricity distribution grid and heating grids if the latter are supplied with heat by large heat pumps. Otherwise, if they are, e.g., supplied by geothermal energy, heating grids are also competing with the natural gas and electricity distribution grid for supplying heat in buildings. In the future transportation sector, gas fueled vehicles supplied by filling stations connected to the natural gas grid compete with electric vehicle supplied by public or private charging stations connected to the electricity grid. Further, in the industry sector, natural gas is used for material use and combustion processes. Some of these processes compete with the direct use of electricity and currently, there is a synergy between the combustion processes and the use of wasted heat feeding into heating grids.

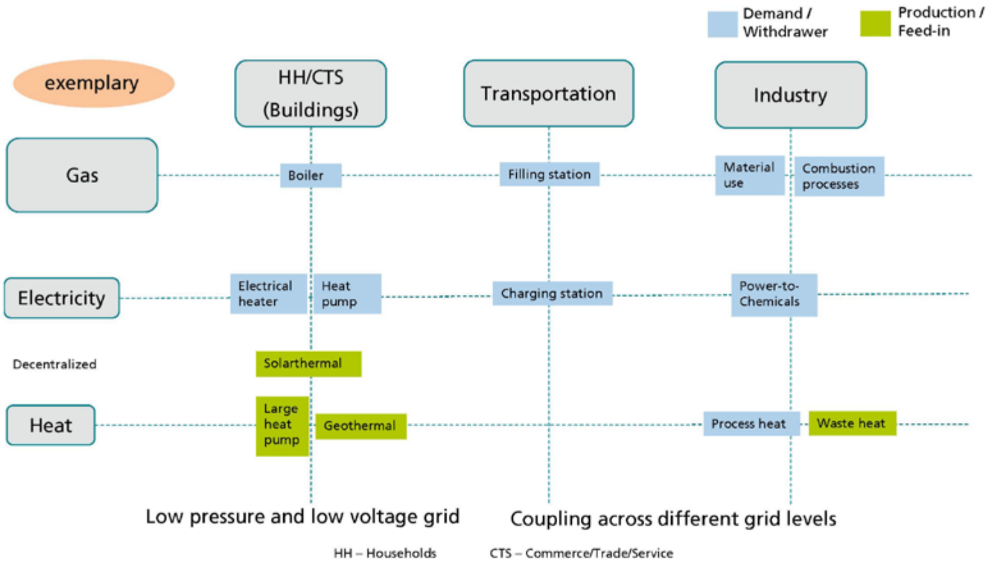

Figure 5: Synergies and competition between heating grids, gas and electricity distribution grids

Taking a closer look into the structure of the different grids, natural gas and electricity grids are composed out of similar grid levels, i.e. low, medium and high pressure or voltage level (Stadtwerke Troisdorf; VSE 2019). On the other hand, such different grid levels do not exist in heating grids (Agora Energiewende 2019; Panos 2009). Comparing the different grid levels on which the coupling technologies are connected to the grids, in the building sector the coupling appears on a similar level, i.e. on low pressure and voltage level, as well as the main consumers of the heat in heating grids are buildings (AGFW 2018). In contrast, considering the industry sector, the coupling appears on different grid levels. Some energy intensive companies are connected to high voltage lines but have a lower natural gas demand, leading to a connection on the low to medium pressure level. Consequently, the grid level on which sector coupling appears in the industry sector is much more diverse than for heating in the building sector. For that reason, the following exemplary comparison will focus on the building sector, comparing the coupling technologies gas boiler, heat pump and heating grid supplied by large heat pump.

Exemplary comparison of the competition in the building sector

In the following exemplary comparison an average single-family house with a living area of 100 m^2 (UBA 2019) and an average heat consumption of 172.3 kWh/m^2a (Walberg 2012), leading to an average annual energy demand of 17,230 kWh/a, is assumed. The investment for the connection of a household to the heating grid depends on the house structure. In literature, costs between 1,500 € and 4,500 € (Walberg 2012; naturstrom 2019) are outlined, so that an average value of 3,000 € is assumed. It is further assumed that the connection costs are constant over time. The investment in gas boiler and heat pump are based on the cost development provided in (Wietschel et al. 2018). Table 2 provides an overview of the CAPEX and specific CAPEX resulting from the investment for the different technology options. The highest costs account for heat pumps, which experience a slight decrease until 2050. Furthermore, the cost of a new gas boiler is decreasing according to the literature.

Table 2: Capital expenditures (CAPEX) of the coupling technologies (Wietschel et al. 2018; naturstrom 2019; Clausen 2012; Walberg 2012)

	Gas boiler	Heat pump (Air)	Connection to the heating grid
Investment 2015 in €	4,370	12,000	3,000
Investment 2050 in €	3,974	8,155	3,000
Lifespan in years	20	25	25
Interest rate in %	5	5	5
CAPEX 2015 in €/a	351	851	213
CAPEX 2050 in €/a	319	579	177
Average energy demand of a house kWh/a	17,230	17,230	17,230
CAPEX 2015 in €ct/kWh	2.0	4.9	1.2
CAPEX 2050 in €ct/kWh	1.9	3.4	1.2

For the operating expenditures (OPEX), the energy prices have to be divided by the corresponding energy efficiency. Therefore, Table 3 holds an overview of the efficiency developments of the technologies selected based on a literature review. The efficiency of gas boilers is assumed to remain constant while heat pumps and large heat pumps experience a strong increase in efficiency due to technology improvements.

Table 3: Development of the efficiency of three exemplary sector coupling technologies and price development assumed of the three grid-based energy carriers (Hirzel 2017; Viebahn et al. 2018; Wietschel et al. 2018; AGFW 2017; BNetzA 2019; dena 2018; BCG and prognos 2018; Öko-Institut and Fraunhofer ISI 2015; Frontier Economics 2017)

		Gas boiler / Gas	Heat pump / Electricity	Large heat pump / Heat
Efficiency in %	**Status quo**	90	300	300
	2050	90	400 - 700	400 - 700
Average price for households incl. taxes in €ct/kWh	**Status quo**	6.1	21.7 (29.9)	8.6
	2050	7.2 - 9.1	27.0 - 29.9	8.6
Average price for households excl. taxes in €ct/kWh	**Status quo**	4.5	10.6 (14.6)	7.2
	2050	5.3 - 6.8	13.1 - 14.6	7.2
Price for synthetic methane excl. taxes in €ct/kWh	**2050**	10.8 - 22.3	-	-

Further, the prices assumed of the different grid-based energy carriers are also included in Table 3 and the resulting prices for the useful energy are summarized in Figure 6. For the first scenario, the current prices for useful energy including taxes and allocations are compared. The electricity price for heat pumps is subsidies, so that the regular electricity price is included in brackets. For 2050, the natural gas and electricity price developments from different studies are considered, showing an increase in natural gas price and a slight decrease in electricity price (Table 3) (BCG and prognos 2018; dena 2018; Öko-Institut and Fraunhofer ISI 2015). For future heat prices, no estimations are available to the best of our knowledge, so that a constant development is assumed. Furthermore, no subsidy for supplying heat pumps with electricity in 2050 is assumed. For the second scenario, the price developments are similar, yet taxes and allocations are excluded. The last scenario takes into account that in an ambitious GHG-reduction scenario natural gas cannot stay in the energy system and consequently, has to be replaced by synthetic methane. Therefore, the PtG/PtL-Calculator from (Frontier Economics 2017) is used to calculate the cost of synthetic methane imported from North Africa. To the costs 0.43 €ct/kWh are added for sales and marketing (Frontier Economics 2017) and a 10 % share of margin is assumed. The taxes and allocations are not included in the comparison, but a constant share of network charges.

		Gas distribution grid		Electricity distribution grid	District heating
		Natural Gas	Synth. Methane		
Network charges share of household price for energy carrier in %	Today	24.9		24.0	-
Price for useful energy incl. taxes in €ct/kWh	Today	6.8		7.2 (10.0)	8.6
	2050	8.0 – 10.1		3.9 – 7.5	8.6
Price for useful energy excl. taxes in €ct/kWh	Today	5.0		3.5 (4.9)	7.2
	2050	5.9 – 7.6	12.8 – 24.8	1.9 – 3.7	7.2

Figure 6: Overview of the operating expenditures per useful energy development in the different scenarios

Finally, the prices as operating expenditures and the capital expenditures are summed up and compared (Figure 7) while costs for maintenance and repair are not taken into account. For the first scenario, it can be seen that households using heat pumps have the highest level of expenditures, even though the electricity price is subsidized. Heat production by natural gas boilers is the cheapest option. However, with an increase of natural gas prices until 2050, producing heat by heat pumps will become the cheapest option.

		Gas distribution grid		Electricity distribution grid	District heating
		Natural Gas	Synth. Methane		
Total expenditures incl. taxes in €ct/kWh	Today	8.8		12.1 (14.9)	9.8
	2050	9.9 – 12.0		7.3 – 10.9	9.8
Total expenditures excl. taxes in €ct/kWh	Today	7.0		8.4 (9.8)	8.4
	2050	7.8 – 9.5	14.7 – 26.7	5.3 – 7.1	8.4

Figure 7: Overview of the total expenditures in the different scenarios

Excluding taxes and allocations leads to a significant cost reduction for heat production by heat pumps, so that it reaches a similar level than heat supplied by heating grids. Nonetheless, the heat production by natural gas boiler remains the cheapest option today. In 2050, the heat pumps are the cheapest option while a gas boiler and heating grid reach a similar cost level.

Lastly, taking the fuel switch from natural gas towards synthetic methane into account, the expenditures for heat production by gas boilers increases significantly. Consequently, it becomes the least attractive option for heat production in new private buildings in 2050.

Summary and Conclusions

In this paper, the scenario comparison showed a strong decrease in natural gas demand until 2050, especially in the building sector, with a shift towards electrification of heat production. Furthermore, an economic comparison showed that there are higher grid expansions in the natural gas distribution grid performed at a lower investment than for the electricity distribution grid. Today the share of charges for the network on the energy price is on a similar level for natural gas and for electricity. Furthermore, a simple comparison of network charges or price is difficult for the three different grids, due to the different market structures. The technical comparison clarified that coupling technologies are on similar grid levels (low pressure and voltage grid) only in the building sector, which favored a more detailed exemplary comparison on this level.

Based on the exemplary comparison, heat produced by heat pumps is nowadays the most expensive solution. Nonetheless, excluding taxes and allocations bring the three heat production options on a similar expenditure level. In 2050, heat production by heat pumps becomes the cheapest option, even when including higher shares of taxes and allocations on the electricity price. By neglecting taxes and allocations, the gap between heat from heat pumps to heat from natural gas boilers and heating grids increases in 2050. Considering a future fuel switch to synthetic methane in 2050 would lead to an even higher increase in expenditures for heat produced by gas boilers. Consequently, it can be concluded that the natural gas distribution grid will become the least relevant grid for suppling heat in new private buildings in 2050.

Critical reflection

This analysis provides a first insight into the different components influencing the different energy distribution grids without the aim of being conclusive. The assumption of constant shares of network charges neglects the effect that a strong decrease in natural gas demand might lead to higher network charges in the natural gas grid. Considering this aspect would lead to even higher prices for heat produced by gas boilers. Furthermore, the projection of price developments and efficiency changes include high uncertainties, opening up a broad span of solutions. The exemplary comparison of heat production with different technologies only includes a standard average house. In reality, the variation of buildings in size, age and insulation differs strongly. Furthermore, the regional differences, such as villages or cities, lead to different challenges for the infrastructure. This analysis only considers new buildings in which the heating technologies does not exist. Further research should also include existing buildings with its limitations to include new heating technologies. Additionally, more detailed research is needed considering hydrogen feed into the gas distribution grid or the switch from natural gas to hydrogen on the gas distribution grid level taking into account the limitations of the demand technologies and the necessary transformation steps towards a hydrogen grid. Considering these additional restrictions and options for the gas distribution grid is necessary to better understand the role of the gas distribution grid in the future energy system in 2050.

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