Shrinking together and pulling apart: the Austrian gas grid by 2040 under declining natural gas demand and increasing domestic renewable gas generation

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Abstract

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1. Introduction

In Europe, the most efficient way of transporting natural gas has been piped and grid-related transport for decades. There are two main reasons for this. First, natural gas has been an extremely cheap energy source due to its unlimited availability through imports from bordering regions. Hence, large quantities of natural gas have been demanded to cover various energy services. Second, the transport of natural gas through pipelines over short and long distances was and is technically efficient and economically cheap because of good flow conditions regarding pressure levels and, thus, transport capacities [1]. In the context of piped natural gas supply, Austria has a long tradition. Austria was one of the first Western European countries connected to natural gas pipelines. The "Trans Austria Gas Pipeline" (TAG) started operation in 1968 and connected Austria with Slovakia [2]. The effects or consequences of this long history of natural gas in Austria are reflected in a high dependence on natural gas in providing energy services [3] and a well-developed natural gas grid throughout the country [4].

However, natural gas grids face an uncertain future, as does the Austrian gas grid. European and national decarbonisation policies are pushing the use of natural gas towards renewable energy alternatives in all energy services. The consequence is a massive reduction in demand for natural gas [5]. It is therefore unclear to what extent gas grids will still be needed. The main objective is to contribute to this discussion by quantifying the scope and size of the Austrian gas grid by 2040 under different decarbonization scenarios. In particular, the goal it to answer the following two research questions:

- How does Austria's natural gas grid today develop from today to 2040 under different decarbonization scenarios, ranging from electrification of most of energy services to importing renewable methane?
- How do customer grid charges change in a gas grid with a dominant supply of domestic renewable gas generation, such as the Austrian grid, while natural gas demand is declining?

The analysis of the Austrian gas grid provides relevant insights for countries with a high potential for domestic renewable gas production in the future, such as Germany, Italy, and France (see in [6]). Furthermore, the relevance of this case study must also be considered from a European perspective. The Austrian gas grid has historically been an important hub for the transmission and distribution of imported natural gas through Europe and provides ample storage capacities (see in [7]). Therefore, changes in the Austrian gas grid might also impact the gas grid of neighboring countries and vice versa.

A mixed-integer linear optimization approach is proposed to answer the research questions. The applied model considers the existing natural gas grid as a starting point and decides whether the grid covers the gas demand and whether domestic renewable gas production (i.e., biomethane) is injected into the grid. The model considers the existing pipelines' age and the necessary replacement investments if they reach their technical lifetime and the option of early decommissioning in case of no or insufficient use of pipelines to reduce grid operating costs. The study of four different scenarios ("Electrification", "Green Gases", "Decentralized Green Gases", and "Green Methane") ensures robustness while covering a wide range of possible future gas volume developments in demand, imports, exports, and generation. Therefore, the scenarios and work must be understood from a "what-if" perspective. The scenarios determine the shares of renewable/natural gas, hydrogen, power, and other energy carriers in the energy system. Based on that, the need for pipelines to transport and balance gas demand and generation is analyzed. No blending is considered. Explicitly, no integrated energy system modeling across energy sectors/carriers or analysis of how fossil fuel-based energy services are decarbonized is done.

The paper is organized as follows. Section 2 provides relevant literature on the topic and the novelties of this work. Section 3 explains the applied method and the four scenarios in detail. Section 4 present the results of the work, while Section 5 provides a synthesis of the findings. Section 6 concludes and outlines future research.

2. State-of-the-art and progress beyond

3. Method

This section describes the methodology of the paper. First, in Section 3.1, the optimization model used is explained in detail. The focus is thereby on the mathematical formulation. However, where meaningful, qualitative explanations are added to give the reader a more complete understanding of the model. These qualitative explanations are used in particular to describe the main decision made by the model between maintaining operation, decommissioning or making replacement investment in existing gas grid pipelines. In Section 3.2, the gas grid in Austria, which serves as the case study in this paper is presented. Then, in Section 3.3, the four different scenarios are shown. Finally, Section 3.4 provides information on the data used, while Section 3.5 takes a critical look at the method and discusses some limitations and their impact on the results.

3.1. Optimization model

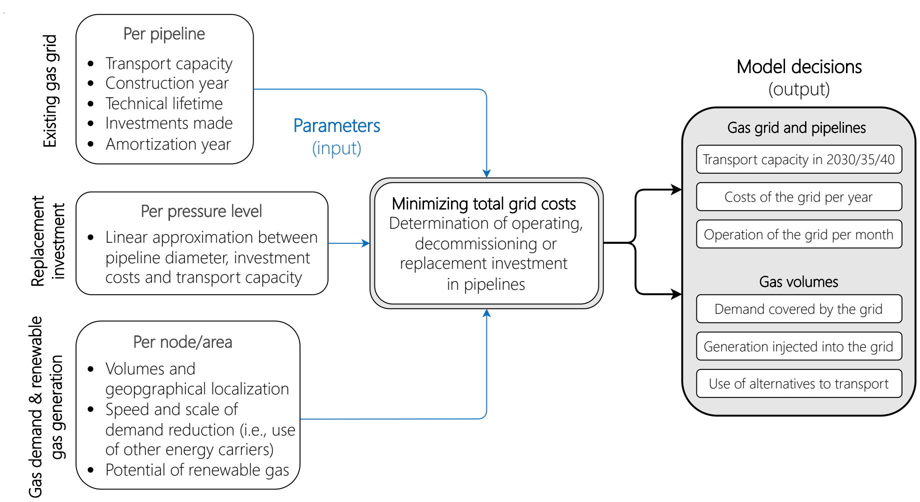


Figure 1

3.1.1. Overview

3.1.2. Objective to minimize total grid costs

3.1.3. Operation, decommissioning or replacement investment in pipelines

3.1.4. Further constraints

3.2. Existing gas grid in Austria

3.3. Scenarios

3.4. Data

3.5. Limitations

4. Results

This section shows the main findings of the Austrian case study. As described above, results for the four scenarios Electrification (Elec), Green Gases (GG), Decentralized Green Gases and Green Methane (GM) are presented. It is structured in three parts. First, Sections 4.1 and 4.2 present the Austrian gas grid in 2030 and 2040 respectively. The quantitative results for grid length, operating and investment costs are presented for both years in detail. Building on this, Section 4.3 focuses on the costs of the grid and shows the grid charges for customers in 2040.

4.1. Austrian gas grid in 2030

The Austrian gas grid in 2030 is shown in Figure 2. The grid, which is the same in all four scenarios, is very similar to the initial grid in 2025 and is only slightly smaller.

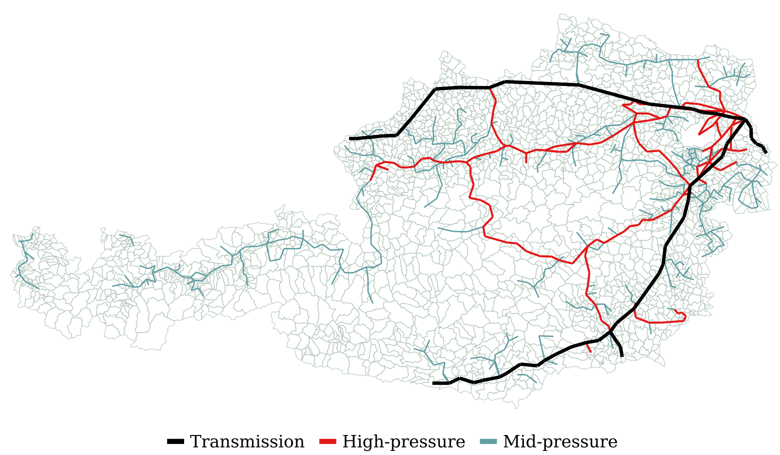


Figure 2: Austrian gas grid in 2030 at the transmission (blue), high-pressure (red) and mid-pressure (green) pressure levels in all four scenarios.

The main reason for the reduction is the use of redundancies and duplicate structures in the grid as a result of declining gas demand. Table 1 shows the reduction in the grid length at the high-pressure and mid-pressure levels in the four scenarios.

	2025	2030			
Pressure level	Initial grid	Elec	GG	DGG	GM
High-pressure	1449 km	−172 km (−11.9 %)	−142 km (−9.8 %)	−142 km (−9.8 %)	−131 km (−9.0 %)
Mid-pressure	3218 km	−283 km (−8.8 %)	−200 km (−6.2 %)	−186 km (−5.8 %)	−208 km (−6.5 %)

Table 1: Absolute and relative reduction in the length of the gas grid at the high-pressure and mid-pressure levels by 2030 compared to the initial grid in 2025. Abbreviations: Electrification (Elec), Green Gases (GG), Decentralized Green Gases (DGG), Green Methane (GM).

The reduction in the grid length at the high-pressure level varies between −131 km and −172 km in the GM and Elec scenarios respectively. The reduction in the grid length at the mid-pressure level varies between −186 km and −283 km in the DGG and Elec scenarios respectively. Removing redundant gas pipelines reduces the operating costs of the grid.[1] The operating costs of the gas grid, which are mainly fixed pipeline costs, decrease compared to the initial grid in 2025 and are around 110 MEUR in all four scenarios in 2030. Note that energy costs for the compressor are not included. By 2030, virtually no gas pipelines are decommissioned due to ageing or because the pipeline is no longer used to transport gas. The assumed young grid age also leads to very low replacement investments into the gas grid. In total, those investments vary by 2030 between 15 MEUR and 18 MEUR in the Elec and GM scenarios respectively. Note that in the model here, replacement investment is necessary when a pipeline reaches its technical lifetime of 75 years. At this point, the model decides whether to invest in replacing the pipeline or to decommission it due to its age.

[1] In reality, these gas pipelines, especially at the transmission and high-pressure levels, can form the core of a hydrogen network. For further details, see for example, the plans for the Austrian hydrogen grid by 2030 published by the Austrian gas network operator [8].

4.2. Austrian gas grid in 2040

The Austrian gas grid in 2040 differs significantly between the four scenarios. Four different gas grids emerge, which are mainly determined by the assumptions of the underlying scenarios. Figures 3 and 4 show the smallest and largest gas grids in terms of grid length.

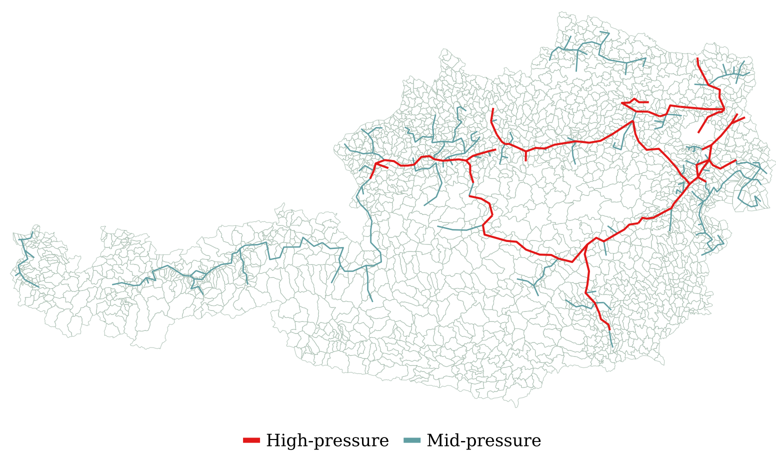


Figure 3: Austria's smallest gas network by 2040 in the scenario Electrification (Elec). Colours: transmission (blue), high-pressure (red) and mid-pressure (green).

The smallest grid is in the Elec scenario and the largest in the GM scenario. The gas grids of the remaining two scenarios GG and DGG are shown in Appendix A. They lie between the two extreme grids in terms of size. Table 2 quantifies the size of the gas grids in 2040 in all the four scenarios by comparing the absolute length of the grids as well as the absolute and relative reduction of grid lengths compared to the initial grid in 2025. In absolute numbers, the reduction of grid length at the mid-pressure level is more significant than at the high-pressure level. In particular, the reduction in the grid length at the mid-pressure level is equally greatest in the two scenarios Elec and GG the greatest with $-1316\,\mathrm{km}$ and $-40.9\,\%$ compared to the initial grid in 2025. The smallest reduction in length at the mid-pressure level among the four scenarios is with

−811 km (−40.9 %) compared to the initial grid in 2025) in the DGG scenario.

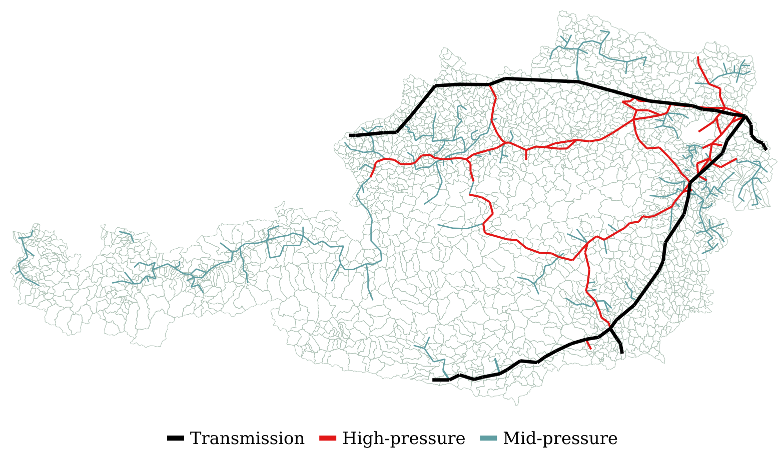


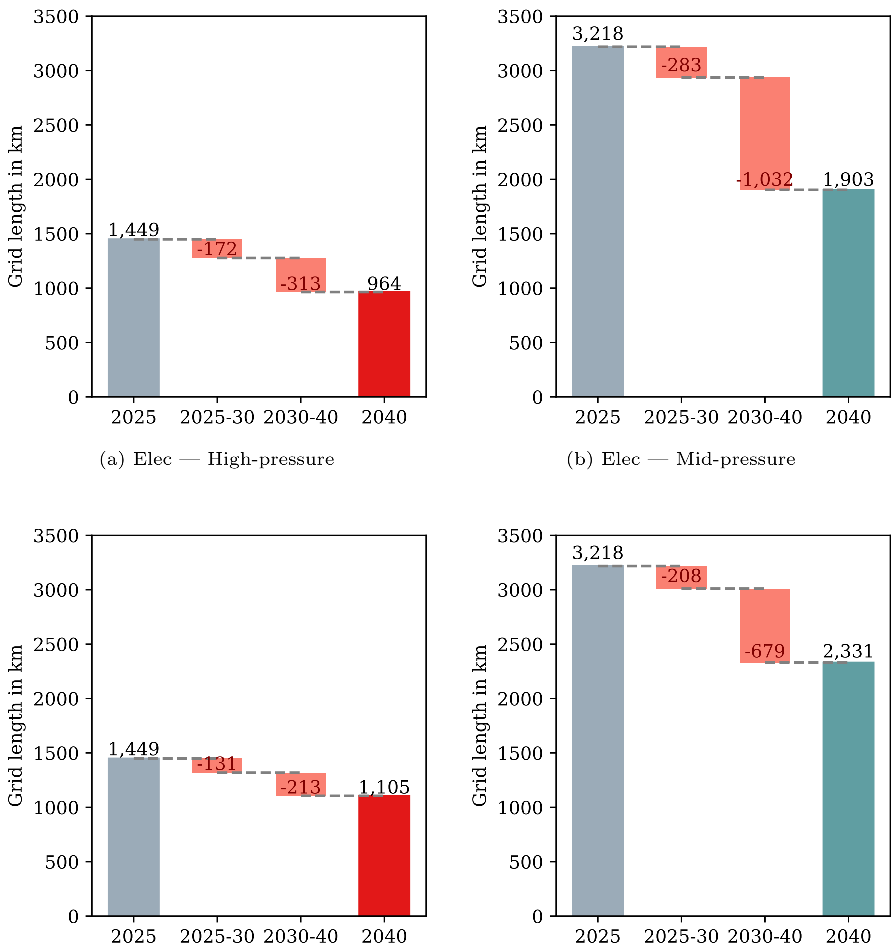
Figure 4: Austria's largest gas network by 2040 in the scenario Green Methane (GM). Colours: transmission (blue), high-pressure (red) and mid-pressure (green).

The main reason here for the relatively small reduction in the mid-pressure grid length is the significant decentralized production and injection of renewable gas.

		2040			
Pressure level	Indicator	Elec	GG	DGG	GM
High-pressure	Abs. grid length in 2040	964 km	965 km	974 km	1105 km
	Abs. reduction to 2025	−485 km	−484 km	−475 km	−344 km
	Rel. reduction to 2025	−33.5 %	−33.4 %	−32.8 %	−23.7 %
Mid-pressure	Abs. grid length in 2040	1902 km	1902 km	2407 km	2331 km
	Abs. reduction to 2025	−1316 km	−1316 km	−811 km	−887 km
	Rel. reduction to 2025	−40.9 %	−40.9 %	−25.2 %	−27.6 %

Table 2: Absolute length of the grids 2040 in the four scenarios as well as the absolute and relative reduction of grid lengths compared to the initial grid in 2025 at the high-pressure and mid-pressure levels. Abbreviations: Electrification (Elec), Green Gases (GG), Decentralized Green Gases (DGG), Green Methane (GM).

The injection leads to an increased use of mid-pressure pipelines. Figure 5 shows the grid length in the two extreme scenarios Elec (top) and GM (bottom) at high-pressure (left) and mid-pressure (right) levels. It highlights the reduction in grid length by 2030 and 2040. The grid length in 2025 is shown on the far left and in 2040 on the far right.



(a) Elec — High-pressure

(b) Elec — Mid-pressure

(c) GM — High-pressure

(d) GM — Mid-pressure

Figure 5: Comparison of the Austrian gas grid in 2025 and 2040 in the scenarios extreme scenarios Electrification (Elec) and Green Methane (GM) at high-pressure and mid-pressure levels. In the Elec and GM scenarios, the smallest and the largest gas grids are obtained in terms of the size of the grids.

The operating costs of the gas grid decrease compared to 2025. They vary between 87.5 MEUR and 93.0 MEUR in the Elec and GM scenarios respectively. 50.0 MEUR (the same in all four scenarios) are accounted for the transmission level. The remaining costs are accounted for the high-pressure and mid-pressure level. Figure 6 shows the total replacement investments in the gas grid in the four scenarios. It includes the replacement investments in 2030 mentioned in Section 4.1 above. The lowest total replacement investments are in the scenarios GG and Elec with 143.0 MEUR and 146.0 MEUR respectively. The highest replacement investments are in the GM scenario with 185.0 MEUR.

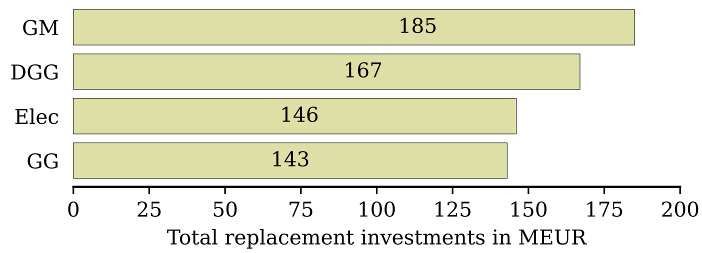


Figure 6: Total replacement investments in the Austrian gas grid until 2040 in the four scenarios.

4.3. Grid charges for customers in 2040

This section presents an analysis of the cost-effectiveness of the gas grid in four different scenarios. The average grid costs are calculated by dividing the total annual grid costs by the gas demand supplied by the grid, and these figures are provided. These average grid costs serve as a basis for estimating grid charges for customers in 2040. It should be noted that determining grid charges based on minimizing system costs is challenging due to regulatory considerations. Nevertheless, regulatory mechanisms often rely on approaches that aim to minimize system costs. Therefore, it is important to consider and interpret the following results from this perspective. In particular, the different grid costs provide a different perspective on comparing the four scenarios.

Figure 7 shows the (average) grid costs in 2040 in the four different scenarios. Note that the horizontal axis is the gas demand supplied by the grid in TWh. The Elec scenario is therefore on the far left, as it has the lowest gas demand of the four scenarios. At the same time, the GM scenario, which has the highest gas demand among the scenarios, is on the far right.

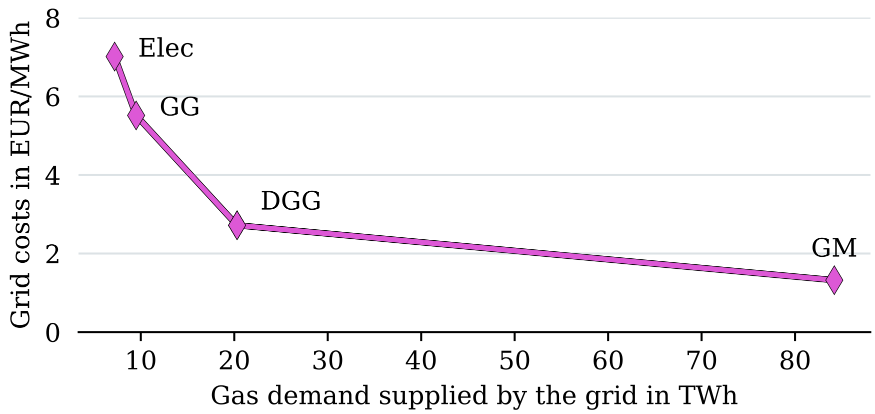


Figure 7: Total replacement investments in the Austrian gas grid until 2040 in the four scenarios.

It is shown that the grid costs are the highest in the Elec scenario with 7.0 EUR/MWh and the lowest in the GM scenario with 1.3 EUR/MWh. The grid costs and its components of operating costs at the different pressure levels and gas demand supplied are summarized in Table 3.

	2040			
Components for calculating grid costs	Elec	GG	DGG	GM
Transmission operating costs in MEUR	0	0	0	50
Distribution operating costs in MEUR	37.5	39.3	40.2	43.0
Capital costs per year in MEUR	13.0	13.1	15.0	18.3
Gas demand supplied in TWh	7.2	9.5	20.3	84.2
Grid costs in EUR/MWh	7.0	5.5	2.7	1.3

Table 3: Average grid costs and their components of operating costs and capital costs. The distribution operating costs encompass the high-pressure and mid-pressure levels. Separation between the transmission and distribution grids result in no transmission operating costs for the customers.

Note that the three scenarios Elec, GG and DGG assume a separation between the transmission and distribution grids (i.e., high and medium pressure levels).

Therefore, the transmission operating costs for customers in these scenarios are zero. Consequently, it is assumed that customers requesting gas transport through Austria at the transmission level bear these costs.

A comparison of the average grid costs with the current grid charges in Austria shows that these are increasing significantly in three of the four scenarios. The current grid charges at the mid-pressure level in Austria are around 1.7 EUR/MWh [9]. Only in the GM scenario do the grid costs remain around or slightly below this value. In the present results of the other three scenarios, the increase in grid costs is driven by the high (distribution) operating costs with comparatively low demand volumes and capital costs. The (annual) capital costs in 2040 result essentially from the replacement investments made by then, which are necessary due to the aging of the (otherwise already fully depreciated) existing grid. As mentioned, a technical lifetime of the pipelines of 75 years is assumed. A possible window for reducing grid costs opens, as a more extended operation of pipelines (e.g., technical lifetime between 90 and 100 years) could reduce the share of capital costs in the grid costs, in extreme cases even make them zero. Such a measure of a longer operating life of pipelines is certainly considered in practice, especially against the background of declining transport volumes. This is because transport volumes determine the operating pressure levels, which determine the pipelines' wear and tear. Lowering the operating pressure levels compared to today's could extend the technical lifetime.[2]. Replacement investments due to aging could be saved. Figure 8 shows the impact on the grid costs if an extension of the pipelines' technical lifetime to 90-100 years is taken into account. The lifetime extension leads to no replacement investments and the current pipelines can remain in operation. The grid costs are consequently going down in all the four scenarios. The highest reduction in grid costs is with -1.8 EUR/MWh in the Elec scenario. The latter is the one

[2]In addition, lowering the operating pressure levels also affects and supports domestic renewable gas generation. On the one hand, generation plants require less energy to compress their gas, and on the other hand, their connection costs are reduced, as the costs are highly dependent on the pressure levels in the grid. For more information from the field, see [10].

with initially the highest grid costs. The smallest reduction in grid costs is with -0.2 EUR/MWh in the GM scenario.

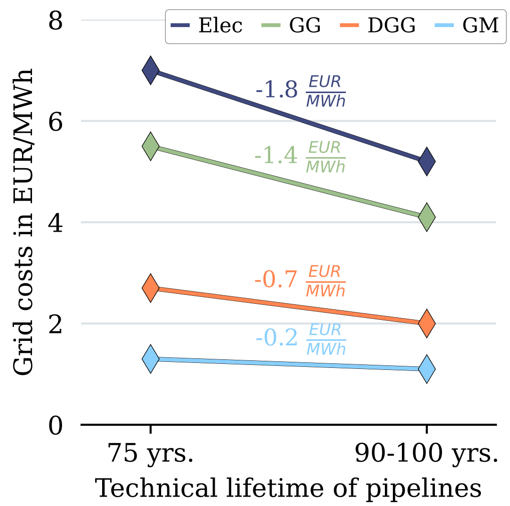


Figure 8: Grid costs in 2040 for a technical lifetime of pipelines of 75 years (left) and 90-100 years (right).

5. Synthesis

6. Conclusions

was es wert diese analyse durchzuführen: nicht nur mengen, sondern auch einspeisung und deren verortung.
die zukunft von erdgasnetzen bleibt eine der spannendsten fragen die sich durch die umsetzung der dekarbonisierung ergibt.
unbestritten, wird es zu einer verkleinerung der erdgasnetze kommen.
auf der fernleitungsebene sehr eindeutig, dass eine umwidmung zu wasserstoff möglich ist, weil kapazitäten vorhanden sind. parallelstränge erlauben es
auf der verteilnetzebene nicht mehr so eindeutig.
doppelstrukturen herauslösen weil netz oft redundanzen hat.
setzt man auf biomethane große netze weiter gebraucht.
dabei kommt es weniger auf die absoluten mengen an, sondern die verteilte einspeisung ist eher eine ja/nein entscheidung
teurere netze, selbst im elektrifizierung noch ein großes netz
schaffen regional/lokal biomethan, genau abgestimmt wo weiterhin verbrauch bleibt
zukünftige arbeiten, diese regionalen cluster zu identifizieren weitere technische details berücksichtigen, wie die druckentwicklung in schwächer ausgelasteten netzen, energie die gebraucht wird um druckhertzstellen, etc.

Declaration of interests

None.

Declaration of Competing Interest

The authors report no declarations of interest.

Acknowledgments

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Appendix A. Detaillierte Gasnetz im Szenario A und B 2040