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Can Industry Keep Gas Distribution Networks Alive? Future Development of the Gas Network in a Decarbonized World: A German Case Study

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Abstract: With the growing need for decarbonization, the future gas demand will decrease and the necessity of a gas distribution network is at stake. A remaining industrial gas demand on the distribution network level could lead to industry becoming the main gas consumer supplied by the gas distribution network, leading to the question: can industry keep the gas distribution network alive? To answer this research question, a three-stage analysis was conducted, starting from a rough estimate of average gas demand per production site and then increasing the level of detail. This paper shows that about one third of the German industry sites investigated are currently supplied by the gas distribution network. While the steel industry offers new opportunities, the food and tobacco industry alone cannot sustain the gas distribution network by itself.

Keywords: synthetic methane; hydrogen; CO_2 transport; industry gas demand; gas transportation network; gas distribution network

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1. Introduction

Global warming and the consequent necessity to reduce global greenhouse gas (GHG) emissions are among the largest challenges for humankind in the 21st century. In the past, significant effort has been invested in reducing GHGs and increasing the efficiency of energy-intensive and fossil fuel-based processes [1]. However, high decarbonization or even complete decarbonization of some sectors has to proceed in hand with intense use of renewable energy and, therefore, an adaptation of production processes. For instance, the current gas-based furnaces of the food and tobacco industry could in the future be replaced by heat produced from renewable electricity [2]. The electrification of these and other processes would imply an increased load on the electricity grid while reducing the demand for natural gas—and, in the long term, other decarbonized gases, such as synthetic methane. At the same time, the demand for methane for heating in households is decreasing and it is likely to remain low or nonexistent in the transport sector [3,4] which will reduce the need for methane even further.

A strong decrease in methane demand until 2050 is a challenge for the gas industry, especially for gas distribution network operators. Investments in gas networks are highly capital-intensive and have very long depreciation periods due to the long lifetimes of the pipelines, with long corresponding capital commitments. In Germany, the transportation network is responsible for long-distance transport and the distribution network for short to medium distances, with industrial production sites being connected to both networks. The capital and operating expenditures of the gas distribution network are almost twice as high as the expenditures of the gas transportation network [5]. With network charges, these expenses are distributed across all network users. Consequently, the higher the utilization of the gas network, the wider the cost can be spread among network users. On the other hand, rather low utilization of the network leads to higher network charges for users [6]. Hence, end-consumer decisions, and especially those of large consumers, such as industrial sites, will have a strong effect on the infrastructure cost and future development for natural gas. Little, however, is known about the end consumers with a high gas demand supplied by the gas distribution network (i.e., certain industries [7,8]), even though this information is crucial for investment decisions in the gas distribution network.

The industrial energy demand has been subject of a wide range of studies. Using long-term scenarios, the authors of [3] investigate three paths towards climate neutrality by 2050, focusing in one scenario on the electrification of the energy system, in another on the use of power-to-gas (PtG) and power-to-liquid (PtL) and in the last scenario on the use of hydrogen. Consequently, three extreme paths are depicted. The authors of [9] also show how Germany can reach climate neutrality but by 2045; hence, the study is aligned with the new climate targets for Germany [10]. This is also the case for [11] and for [12]. While the authors of [3], [9] and [11] focus on macroeconomic analysis, the authors of [12] take a microeconomic perspective. Overall, these studies investigate the potential of the various industry branches for electrification, application of hydrogen or increased efficiency. However, only [3] models the gas distribution network and assumes shares of industry demands supplied by the gas distribution network.

In their hydrogen strategy 2.0 for Germany, the authors of [7] identify areas in which action is needed for a quick hydrogen market ramp-up. In addition to the need for a nationwide strategy decision about the future of the gas distribution network, the authors point to the need for intensive analysis regarding the different spatial structures of the gas distribution networks. In particular, the differentiation between distribution and transportation network operators supplying consumers with a large natural gas demand is not very distinct. This need for specification is also pointed out in [8], in which the authors detect limiting clauses and gaps in regulations on the European level for the market entrance of new gases, such as hydrogen.

Studies investigating the future role of the gas distribution network have the same challenge of differentiating between industry gas demand supplied by transportation and distribution network [13–16]. In [13], alternative pathways for supplying buildings with heat are investigated based on two deep-decarbonization scenarios focusing on electrification of the heat supply and on the usage of heat networks. Commercial building heat demand includes small industries but is not further specified. The authors of [14] investigate the decarbonization of the heating sector and its implications for the gas distribution network based on a meta-analysis of existing studies and their own network planning with representative typical networks. In this study, the assumption is made that a maximum of 35% of industrial and commercial gas demand is supplied by the gas distribution network without further investigating the industrial branches. The authors further point out that certain industrial processes do lack in alternatives to gas usage. The impact of decreasing gas demand on the strategies of gas distribution network operators—and, hence, the gas distribution network charges—is analyzed in detail in [15]. However, the analysis focuses on the building sector and the industry gas demand is assumed to be mainly supplied by the transportation network. In contrast, the authors of [16] point out that some of the industrial gas demand is supplied by the gas distribution network and they assume that this would be 35% of the total industrial gas demand. Further, the authors assume that the gas demands of the industry branches of steel production, metal production, basic chemistry and glass and ceramics are supplied by the gas transportation network.

These studies provide comprehensive insights into the future of the gas distribution network with a focus on the building sector. However, to the best of the knowledge of the authors of this paper, detailed assessments of the effect of industrial gas demand on the gas distribution network are lacking in the current literature. This leads to the danger of underestimating the future role of the gas distribution network in some regions with a high share of industrial gas demand. Furthermore, as already pointed out in [14], some industrial processes do not have alternatives to gas usage and, hence, might even rely on supply from the gas distribution network in the future. Thus, little is known concerning the industrial demand for gas that might remain due to process requirements, especially at the distribution network level.

Therefore, in this paper, we provide a novel view of the shares of different industry branches supplied by the gas transportation and distribution networks in a case study for Germany. Further, to gain insights about the remaining industrial gas demand in a decarbonized energy system in Germany up to 2050, alternatives to gas usage in the different industrial branches are investigated and the timeline of their implementation is derived. Lastly, the implications for the gas distribution network of the alternatives to gas usage in the different industry branches are highlighted and alternative usage options for the gas distribution network are identified. This leads to the following research question, which is unanswered in the existing literature:

Can industry keep gas distribution networks alive?

To answer this question, some background information on the status quo among gas end-consumers and gas network operators is first provided in Section 2. In this section, the six most important industry branches for methane demand in Germany are derived. Then, the investigation approach, data and assumptions are explained in Section 3. In Section 4, we determine the numbers of production sites that cannot be easily connected to the transportation network per industry branch. Then, we analyze the future gas demand in these branches based on current and future technologies. Finally, our findings are summed up and discussed and a conclusion is drawn in Section 5.

2. Status Quo of Gas End-Consumers and Gas Network Operators

In the following, the end consumers relevant for the gas network and the structure of the gas network are described.

2.1. The Gas End-Consumers

In the EU, Germany accounts for the highest natural gas demand, with 1,009 TWh in 2021 [17]. Italy consumes the second highest amount of natural gas, with 805 TWh in 2021, and France, which consumes about half of the German natural gas demand, is the third highest consumer of natural gas in the EU [17]. Hence, in the following, we take a deeper look into the end-consumer structure of Germany.

The total energy demand in Germany is generally divided into three sectors: about 30% of German annual energy demand originates with each industry and the transport sector, while the buildings sector (households and service sector) needs 40% [18]. All gases contribute 25% to the total German energy demand. While the demand for gases in the transport sector is of less importance today, about 40% of the annual energy demand in industry and the buildings sector is met by gases [18]. Gases nowadays mainly originate from natural gas and by-product gases from steel production.

Various studies investigating the future German methane demand (natural gas and synthetic methane) in the buildings, industry and transport sectors [3,9,11,12] have found a strong decrease in the buildings sector (Figure 1), with more houses being equipped with heat pumps or connected to a district heating network. For the future gas demand in the industry sector, most of the studies compared in Figure 1 see a strong decrease as well. Only in the dena Lead Study was it found that 60 TWh of methane demand would remain in 2050 [11], while the climate-neutral scenario with a focus on power-to-gas/power-to-liquid (TN-PtG/PtL) from Fraunhofer ISI even showed an increase in methane demand in industry up to 300 TWh by 2050 [3]. This study was undertaken before the decision by the German Federal Supreme Court to announce the current German climate protection law unconstitutional [19]. According to the new climate targets, the GHG emissions need to be reduced by 65% by 2030 and, by 2045, a climate-neutral German energy system needs to be achieved [20]. Nonetheless, the insights gained from the Fraunhofer ISI study are still valid, but it is important to point out that only the electricity scenario (TN-Electricity) is close to achieving the new climate targets.

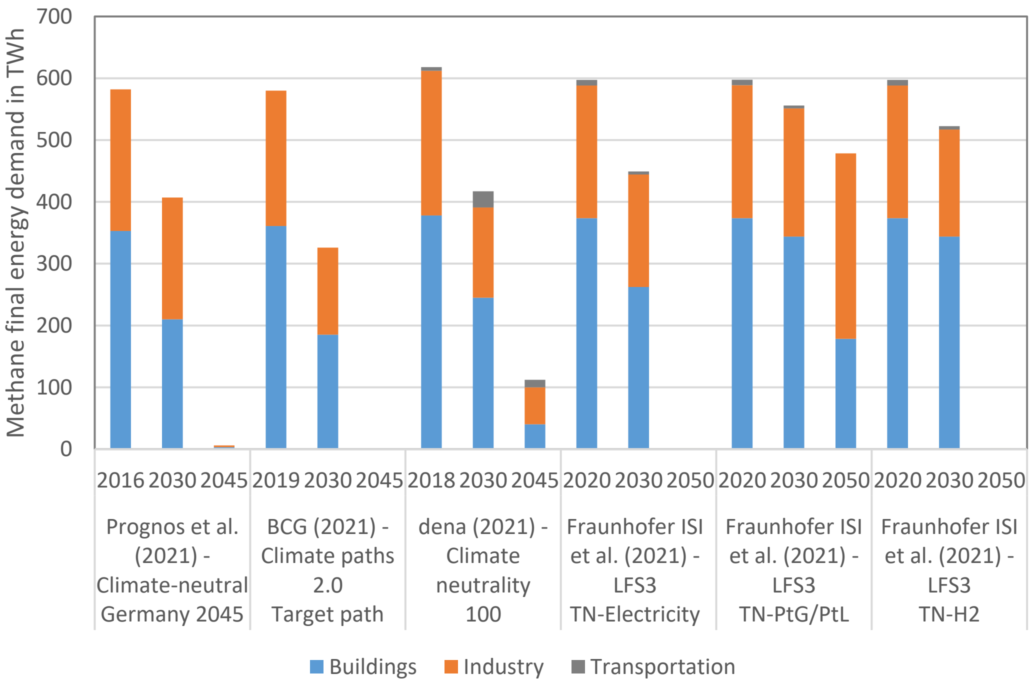

Figure 1. Development of the methane final energy demand in TWh. Authors' illustration based on [3,9,11,12].

Today, German industry employs about 218 TWh of energy produced from natural gas [21]. The majority is required for process heating (85%) (see Figure 2). With 49 TWh for process heating in 2019, the basic chemicals industry is responsible for almost one quarter of the total natural gas demand. It is followed by the food and tobacco (27.6 TWh), pulp and paper (19.4 TWh), iron and steel (17.4 TWh), glass and ceramics (15.9 TWh) and mineral processing (11.9 TWh) industries. Together, these six industry branches are responsible for about 69% of the total natural gas demand in industry.

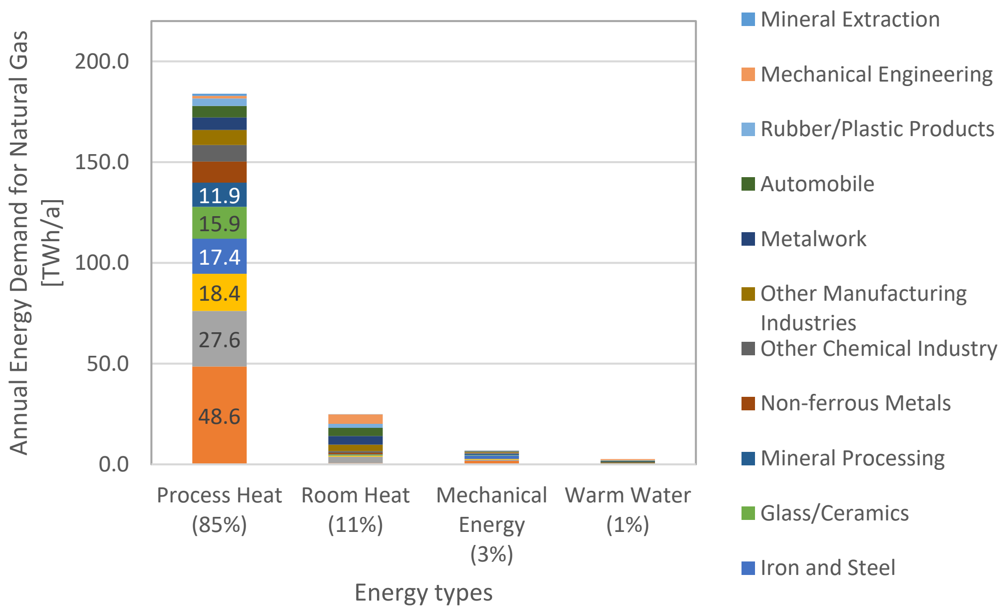

Figure 2. Annual natural gas demand in industry in 2019. Authors' illustration based on [21].

2.2. Structure of the Gas Network Operators

In the EU, the gas transport network has a length of 200,000 km, and its worth amounts to around EUR 65 billion in asset bases owned by transmission system operators (TSOs), also named transportation network operators (TNOs). With an asset base worth three times more than the TNO asset base, the distribution network owned by the distribution network operators (DNOs) reaches a length of 2 million km [22]. With 522,100 km (in 2019), more than a quarter of the EU distribution network is located in Germany [5].

The German gas transportation network differs structurally from the gas transportation networks in other European countries. In contrast to other countries, its parts have grown together regionally in the private sector over the past [23]. In Germany, there are currently 16 TNOs [5], whereas Austria has 7 TNOs, France 2 and the Netherlands, as well as Great Britain, only has 1 [23]. The more than 700 DNOs add further complexity to the German gas network [5,23].

According to §3 no. 31c of the German energy economy law (EnWG), a TNO equals a transmission system operator (TSO), which is further specified in §3 no. 5 of the EnWG as an operator of a network with crossing points over a border or market area, integrating large European import pipelines into the German transmission network. Further TSOs have to be certified by the regulatory authority (EnWG §4). Local distribution networks are defined as those that predominantly supply end consumers via local pipelines, regardless of the pressure level or diameter of the pipelines (EnWG §3 29c) [24].

In 2019, the overall transportation network length in Germany was 33,600 km, comprised solely of high-pressure pipelines above one bar [5]. On the other hand, the length of the German distribution networks adds up to 522,100 km, of which 76,200 km is comprised of high-pressure pipelines above one bar [5]. To conclude, the distribution network is capable of supplying end consumers with very high gas demand, as well as those with a lower gas demand, according to the technical properties and its definition by the EnWG.

According to a survey of distribution and transportation network operators conducted in [5], household consumers can be clustered in consumer groups with annual demands between 5,556 kWh and 55,556 kWh. For consumers in the service sector, they assume an average annual demand of around 116 MWh, and for industry consumers, an average annual demand of 116 GWh. With regard to Table 1, the first category of end consumers (≤300 MWh/a) mainly includes households and some consumers from the service sector. The second category (>300 MWh/a ≤10,000 MWh/a) includes a mix of consumers from the service and industry sectors, and the other categories solely include consumers from the industry sector. The first two categories of end consumer are mainly supplied by DNOs, whereas the last two consumer categories (>10,000 MWh/a; ≤100,000 MWh/a; >100,000 MWh/a) are supplied by both DNOs and TNOs.

Table 1. Gas withdrawal volume in 2019 by category of end consumer [5].

Category of End Consumer	TNO Gas Withdrawal Volume in TWh	DNO Gas Withdrawal Volume in TWh
≤300 MWh/a	<0.1	336.6
>300 MWh/a ≤10,000 MWh/a	0.5	28.4
>10,000 MWh/a ≤ 100,000 MWh/a	5.9	111.0
>100,000 MWh/a	137.9	131.8
Gas power plants with ≥10 MW net nominal capacity	42.5	56.7
Total	186.9	764.5

These categories are used in the next sections to allocate the various industrial branches to the gas transport or distribution networks. For this purpose, the average gas demand per production site of the various industry branches is first calculated, and then they are grouped accordingly. The next section describes the methodological procedure in detail.

3. Methods and Data

3.1. Methodical Approach

This paper provides a three-stage analysis starting with a coarse analysis and then increasing the level of detail with a geographical analysis of production sites and a discussion of future gas development. This approach is sketched out in Figure 3, illustrating in dark blue the rather rough estimation of the network connection level based on supplied gas per production site. In blue, the next, more detailed level of the geographical assessment of the industry production sites and the gas transportation network is depicted. Lastly, in light blue, the most detailed investigation concerning the alternatives to gas usage in the different industry branches and their timeline is shown.

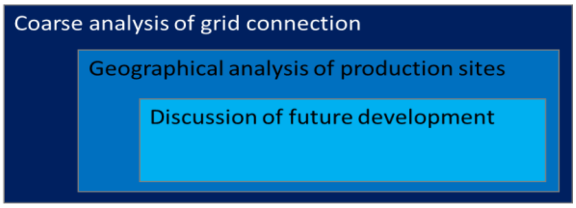

Figure 3. Overview of investigation.

As a first step, a rough estimate of the network level supplying the industry branches selected in Section 2.1 is outlined. The application balance of industry and trade for the German energy balance [21] provides the current natural gas demand in different industry branches on a national level ($d_{national,x}$) and, hence, the demands affecting the gas transportation and distribution networks. For other EU countries, energy balances can be found in [25]. To separate these demands based on their supplying network level, the geographical locations of the industrial production sites investigated were mainly taken from the Fraunhofer ISI Industrial Site Database [26], which is explained in more detail in Section 3.2. This database provides the number of production sites for each industry branch (n_x). Based on the annual gas demand of the industry branches at a national level from [21] and the number of production sites, based on [26], the average gas demand per production site can be calculated as shown in Equation (1):

$$d_{average,x} = \frac{d_{national,x}}{n_x} \quad (1)$$

$d_{average,x}$ is the average gas demand per production site in the industry branch x;
$d_{national,x}$ is the current national gas demand of the industry branch x;
n_x is the number of production site of the industry branch x.

This average gas demand per production site can be categorized similarly to the consumer categories in [5]. Production sites in the first two categories tend to be supplied by DNOs, whereas production sites in the other consumer categories (>10,000 MWh/a) can be connected to both the transportation and distribution networks.

In the second step, the locations of the production sites from [26] are compared to the location of the German gas transportation network to provide clearer insights, especially into the consumer categories supplied by both transportation and distribution networks. Production sites located close to the gas transportation network tend to be supplied by this network or can easily be connected to it, whereas production sites located further away from the gas transportation network tend to be supplied by the gas distribution network and can only be connected to the former with difficulties. “Close” is here defined as less than 7 km and "further away" means equal to or more than 7 km. This approach can be applied to any other European country by using the gas transportation network map from ENTSOG [27].

The third and last step is to identify the potential for switching from gas-based processes to alternatives and to provide a timeline for switching for the industry branches supplied by the gas distribution network. This is performed using a qualitative analysis of alternative production processes based on the existing literature and their technology readiness levels (TRLs) defined in [28], while the timelines are based on the long-term scenarios of the German Federal Ministry of Economics and Climate Protection (BMWK) [3]. Section 3.3 explains the assumptions underlying these scenarios.

3.2. Data

More detailed information about the number of industry production sites and their locations is provided in the Fraunhofer ISI Industrial Site Database [26]. For the identification of the industrial production site connections to the gas distribution or transportation networks, the important information in this database is the geographical information, the industrial subsector and the manufactured products at each site.

The overall methodology of the Fraunhofer ISI Industrial Site Database is described in [29], and more detailed information on the data included and their level of detail is provided in [30]. Based on these sources, further development and in-depth analyses are already available for the scope of Germany in [26] and are used in this paper.

In total, the database includes 5,440 industrial sites for the different EU member states and the United Kingdom [30]. For Germany, the final database consists of 371 industrial sites, listing information about 656 plants with 37 different processes [26]. The base year is 2015 and, where possible, data have been updated to 2017 or at least 2018.

3.3. Scenarios for Future Industrial Energy Demand

To provide insight into the timeline for switching production processes, the scenario pathways with a focus on power-to-gas/power-to-liquid (PtG/PtL) and on electricity in [3] were chosen. Both scenario pathways are based on the same assumptions concerning economic development, energy and material efficiency and progress in the circular economy. The main differences are summed up in Table 2.

Table 2. Overview of differences between the PtG/PtL and electricity scenario in the long-term and climate scenarios of the BMWi [3].

	PtG/PtL	Electricity
Advantages	Little adaptation of infrastructure and demand side	No losses due to conversions from renewable electricity in electrolysers for hydrogen production or other syntheses towards PtG/PtL, and partly higher efficiencies for electrified processes
	Fossil hydrocarbons can be gradually replaced by synthetic hydrocarbons by steadily increasing blends	Carbon is only needed for production in the chemical industry and there is no need for CO_2 infrastructure
Disadvantages	Significantly higher demand for electricity from renewable sources; importing the majority of synthetic fuels from non-EU countries	Significant differences will arise in the energy supply on the demand side and necessary process changes will occur
	Carbon demand requires direct air capture and additional CO_2 infrastructure	Further electricity transportation infrastructure requirements will be significant
	PtG and PtL are associated with high costs	Industrial feedstock uses a hydrogen network serving about 20 industrial sites

In both pathways, the industrial sector achieves GHG reductions of about 97% by 2050 compared to 1990 [3]. The remaining GHG emissions of about 7 Mt are almost exclusively process-related. Although these will continuously decrease up to 2050 due to process changes, material efficiency, carbon capture and utilization (CCU) and the use of innovative cement types, a significant base will still remain in these areas. The authors of [3] provide further, more detailed information about the assumptions and scenario results.

4. Industry Sectors with Large Natural Gas Demand and Their Future Development

The industry branches investigated in more detail in this section consumed about 69% of the total industrial gas demand in 2019, as derived in Section 2.1. Table 3 provides an overview of the industry branches and roughly estimated network connecting levels, as well as their different gas demands and numbers of production sites and the resulting average gas demand of single production sites used to estimate the network connection level. With 5,984 MWh in 2019, the production sites of the food and tobacco industry required the lowest average amount of gas and, hence, are grouped into the second lowest consumer category in [5]. Consequently, the food and tobacco industry is supplied with natural gas by the gas DNOs. The basic chemicals industry consumes by far the highest amount of natural gas per production site, with 1,758,622 MWh in 2019, leading to the conclusion that its production sites are supplied by gas TNOs. For the other industry branches, the average gas demand per production site suggests their categorization into the two highest consumer categories; thus, for a clearer understanding of their network connection level, their locations have to be analyzed in more detail.

Table 3. Annual natural gas demand of different industries in 2019, their natural gas demand per production site and their assumed network level. Sources: [1,5,18,21,26,31,32].

Industry	Basic Chemicals	Iron and Steel	Food and Tobacco	Pulp and Paper	Glass and Ceramics	Mineral Processing
Total natural gas demand 2019 (TWh/a)	51.0	19.1	31.7	19.3	16.7	12.9
Number of production sites	29	30 *	5,292	170	414	104
Average natural gas demand per production site (GWh/a)	1,758.6	637.9	6.0	113.2	40.2	123.9
Categories of end consumers according to [5] (MWh/a)	>100,000	>100,000	>300 ≤10,000	>100,000	>10,000 ≤100,000	>100,000
First assumptions of gas network level	Transportation	Transportation/distribution	Distribution	Transportation/distribution	Transportation/distribution	Transportation/distribution

* Production sites include primary and secondary routes, as well as further processing sites [33].

4.1. Iron and Steel

In Germany, iron and steel are produced at around 30 production sites. The most important one is located in Duisburg, North Rhine-Westphalia, which accounts for 35% of German steel production [33].

Coal accounts for two thirds (81.1 TWh) of the total fuel consumption in the iron and steel industry [21,33], followed by other gases, with consumption of 26.1 TWh, and natural gas, with 19.1 TWh [21]. Two steel production routes can be differentiated. The primary route, accounting for around 70% of the production in Germany, uses iron ore and coal to produce crude steel. In the secondary route, steel scrap is melted with an electric arc; hence, this route has a low impact on the gas networks [33].

Figure 4 provides an overview of the seven primary steel production sites, grouping the production sites in North Rhine-Westphalia as one production site. Among these sites, five (out of seven) are not connected to the gas transportation network. Consequently, it can be assumed that these steel production sites are connected to a gas distribution network.

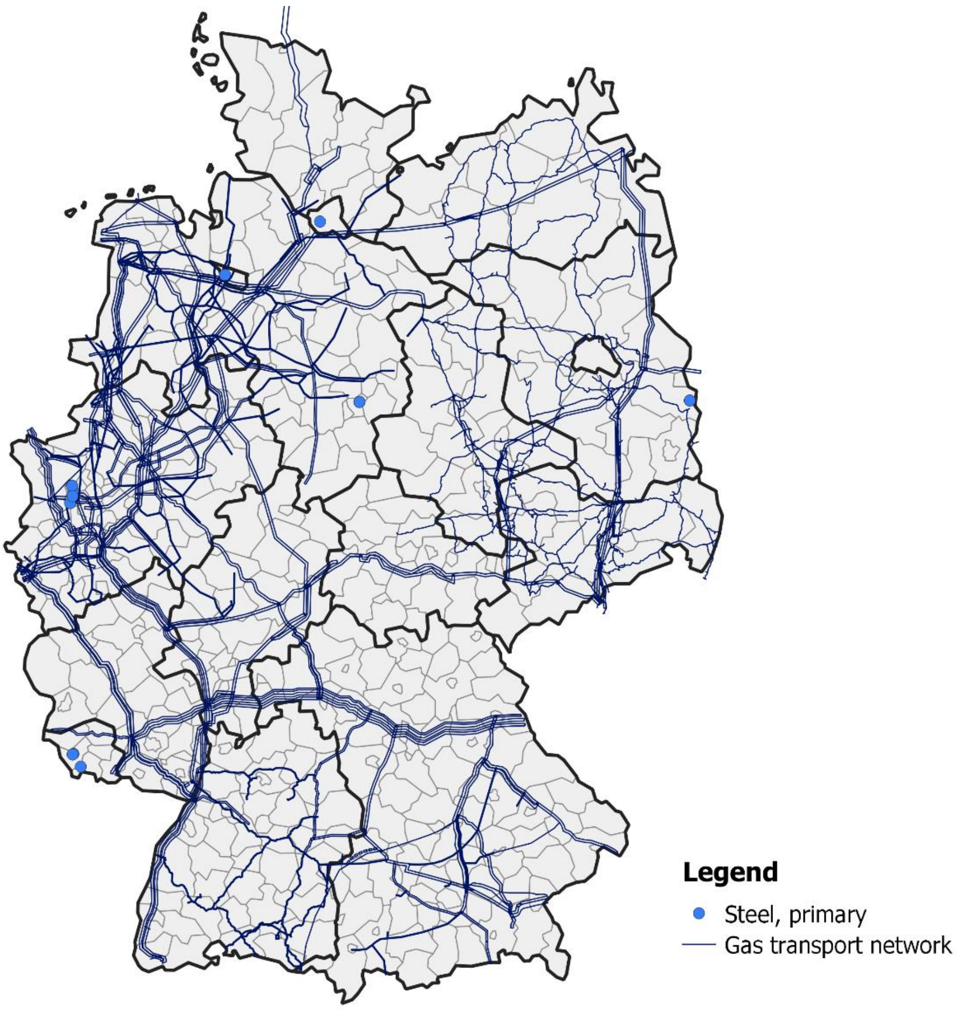

Figure 4. Steel production sites in combination with the current gas transportation network. The multiple blue lines show the redundant structure of the German gas transportation network; hence, more than one pipeline supplies the different regions. Based on [26,34] and updated from [27].

The secondary route of steel production can be nearly CO_2 neutral when using biomass and renewable electricity [32]. The decarbonization of the primary route is a larger challenge. In this route, coal is used to produce coke, which is applied as a fuel and reduction agent in furnaces [32,33]. As an alternative, hydrogen can be used instead of coke in the direct reduction process, leading, however, to the need for a completely different process and, hence, investment in a new production line [32]. Other emission-reduction technologies include iron electrolysis, which is highly electricity-intensive but does not require any carbon-reduction agents, and the combination of processes with CCS or CCU (TRLs 3–6) [32,35].

The German hydrogen strategy states that hydrogen is the most promising decarbonization option for the steel industry, and Thyssenkrupp, as owner of the steel production in Duisburg, has already announced its plans to become climate-neutral by 2050 [36,37]. In the study for the European Hydrogen Backbone, the switch to hydrogen in the German steel industry was expected to start with a demand of 18 TWh/year up to 2030 [37]. For 2040, this demand estimation increased significantly to 50 TWh/year and further to 60 TWh/year by 2050 [37].

The electricity pathway of the long-term and climate scenarios described in Section 3.3 shows similar development but with a later and slower start for the switch to hydrogen. In the pathway, the ramp-up of hydrogen demand starts with 5 TWh in 2030, increases to 23 TWh by 2040 and reaches 40 TWh in 2050 [3]. In contrast, the PtG/PtL pathway assumes a switch from natural gas to synthetic methane [3].

Overall, primary steel production in Germany can be identified as one of the first movers for the ramp-up of the hydrogen market and the construction of a hydrogen infrastructure partly based on retrofitted natural gas pipelines in Germany [38]. Hence, the retrofitting of the gas distribution network for primary steel production sites to a hydrogen network, which would consequently lead to new business opportunities for the local distribution network operator, should be considered.

4.2. Food and Tobacco

In the food and tobacco industry, natural gas is mainly applied for process heating, such as drying, pasteurization, sterilization, cooking and evaporation processes [1], leading to the second highest natural gas demand in the industry sector, with 31.7 TWh in 2019 [21]. The sector is highly diverse, so a detailed analysis is hardly possible. The authors of [2] identify nearly 5,300 production sites all over Germany, leading to an estimation of a specific natural gas demand of 5,984 MWh/a per production site. A detailed overview of the locations of the production sites cannot be provided but, based on the average gas demand per production site, supply through the gas distribution network can be assumed.

According to [1], the dairy industry and the processing of baked goods, sugar, and meat have the highest energy demands, altogether accounting for 41% of the total energy demand in the food and tobacco industry. Their typical temperature requirement is below 150 °C, while drying (e.g., of milk powder) requires temperatures up to 300 °C [39,40]. Natural gas is required to fuel the rotary drum furnaces in the drying process and the ovens for baking (120 °C to 180 °C) in bakeries, as well as for hot steam production for cooking, scalding and smoking in the meat industry [1,2].

For a highly decarbonized future, a complete shift towards electricity-based process heating and waste heat usage is assumed in various studies [41,42]. Microwave heating, (e.g., for pasteurization), infrared heating, electric ovens and industrial heat pumps are alternatives to natural gas-based heat production and already available at a high TRL (TRLs 7–9) [2]. Further, the use of waste heat fed into a heating network in combination with heat pumps can decrease the demand for natural gas [1].

This development is also shown in the electricity pathway of the long-term and climate scenarios described in Section 3.3. In the period from 2019 to 2030 already, the natural gas demand will drop by nearly half, from 31 TWh to 18 TWh, and by 2050, nearly no methane demand will remain [3]. On the other hand, the PtG/PtL pathway focuses on synthetic methane usage instead of electrification, but even with this focus, the methane demand will decrease by 30% compared to the methane demand in 2019 [3].

In conclusion, there are manifold options for the provision of process heat in the food and tobacco industry. Today, process heat is mainly provided by natural gas, but current studies assume a shift to electricity-based heat production in a highly decarbonized future, and even in scenarios with a positive setting for synthetic methane usage, the gas demand decreases. Considering the number of production sites spread across Germany, we assume that the production sites are connected at the gas distribution network level and, hence, the decreasing gas demand will have a meaningful effect on the DNOs.

4.3. Pulp and Paper

Overall, 170 paper production sites exist across Germany [26], and only 6 of them are integrated plants with biomass-intensive production of chemical pulp [43]. However, the energy demands of the different paper factories vary strongly depending on the type of paper produced [1,43]. Figure 5 gives an overview of the pulp and paper production plants in combination with the existing gas transportation network. About 51 (of 170) production plants seem to be located further away from the gas transportation network; hence, they are supplied by the gas distribution network. These plants accounts for almost one third of the pulp and paper industry.

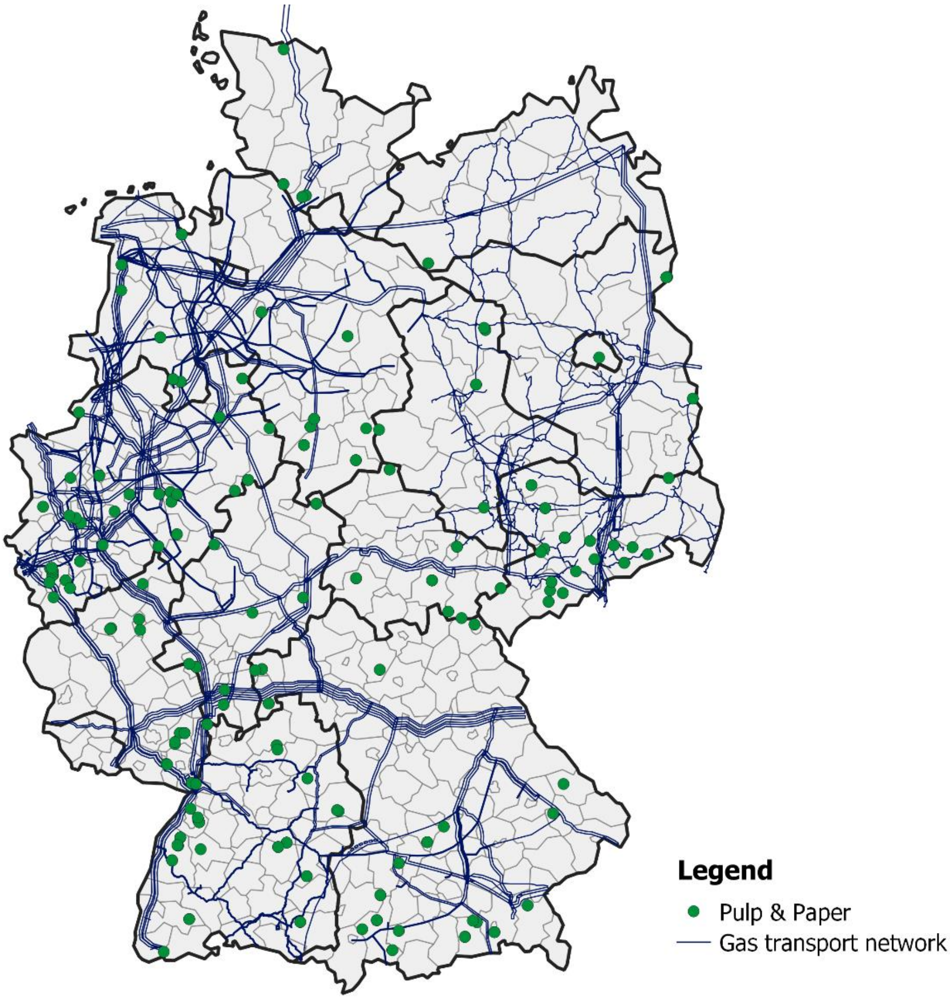

Figure 5. Pulp and paper production sites in combination with the current gas transportation network. Based on [26,34] and updated from [27].

In 2019, the pulp and paper industry had an overall natural gas demand of 19.3 TWh [21], which was predominantly for the production of steam for drying and calendering processes within the paper production phase [44]. The preceding phase (i.e., the production of chemical pulp, mechanical pulp or recovered fibers) relies mainly on biomass (e.g., waste from the paper production) and electricity [1,45]. In the drying process, the paper lanes run through steam-heated cylinders, which operate at around 140 °C, depending on the type of paper. Afterwards, they are calendered at temperatures between 80 °C and 400 °C, for which either hot water, steam or thermal oil is applied [44].

In 2019, the energy demand of the pulp and paper industry was composed of 34% natural gas, 31% electricity and 13% district heating [21], leading to high competition among the network-based energy carriers [46]. In addition to more efficient drying processes, the use of waste heat and the optimization of the heat flows within paper factories have the highest potential for further CO_2 emission reductions [1]. In pulp production, almost half of the wood input is burned to produce heat and electricity in CHP plants (TRLs 8–9), leading to high biomass potential and representing a source of waste heat that could be used to supply district heating networks [1,47].

The strong competition between the three networks—natural gas, electricity and district heating—can also be observed in the long-term and climate scenarios described in Section 3.3. In the electricity pathway, the natural gas demand will be phased out by 2050, with a demand decrease of 40% compared to 2019 by 2030 [3]. In contrast, the methane-focused pathway (PtG/PtL) shows a drop of about 35% between 2019 and 2030, but synthetic methane demand will increase to 18 TWh by 2050 [3].

Overall, the available alternative options and the scenario developments described will create challenges for the gas DNOs in regions where the pulp and paper industry is mainly supplied by DNOs, which account for around one third of the pulp and paper industry. Even in the PtG/PtL pathway, the gas demand will decrease in the medium term before increasing in the long term, leaving the question of whether local DNOs can survive a certain time with lower gas demand open to further analysis.

4.4. Glass and Ceramics

The high energy demand of the glass and ceramics industry is mainly covered by natural gas, with a consumption of 16.7 TWh in 2019 [21]. Almost 75% of the natural gas is consumed by glass factories [1], so the focus in this paper is glass production. In 2019, container glass had the highest production rate with 55% of the total glass production, followed by flat glass with 27% [48].

Figure 6 illustrates the locations of production sites for container glass (dark red) and flat glass (light red). Ten of the eleven flat-glass production sites are located close to the gas transportation network and only one is located further away and, hence, supplied by the gas distribution network. A total of 28 container-glass production sites are included in the analysis and about 12 of them are located at a distance from the gas transportation network, grouping the 5 production sites in Thuringia together as one. Consequently, these 12 container-glass production sites (43%) are supplied by the gas distribution network.

The glass industry is highly heterogeneous in its products and its production volume and energy demand vary [49]. Nonetheless, the production process is almost identical until the shaping process. The melting process, mainly fueled by natural gas, accounts for between 50% and 85% of the total energy demand of glass factories and reaches temperatures between 1,450 °C and 1,650 °C [1,49]. Smaller melting furnaces can be completely electrified (TRLs 7–9), but larger ones are mainly fueled by natural gas [50,51]. The high temperature level limits the potential for using renewable energy, such as solar thermal energy, heat pumps and CHP plants [47]. However, research has been conducted on the possibility of the electrification of container glass production using large, hybrid electric melting tanks powered by 80% renewable electricity and 20% natural gas (TRLs 2–4) [50,52]. Further, the application of hydrogen is considered critically, as it would lead to the corrosion of glass [53]. Nonetheless, in the HyGlass research project, the shift from natural gas to hydrogen in glass production was investigated [54]. Further, there is the possibility of using synthetic methane produced by an electricity-based methanization process; however, the high fuel cost would make this challenging [49].

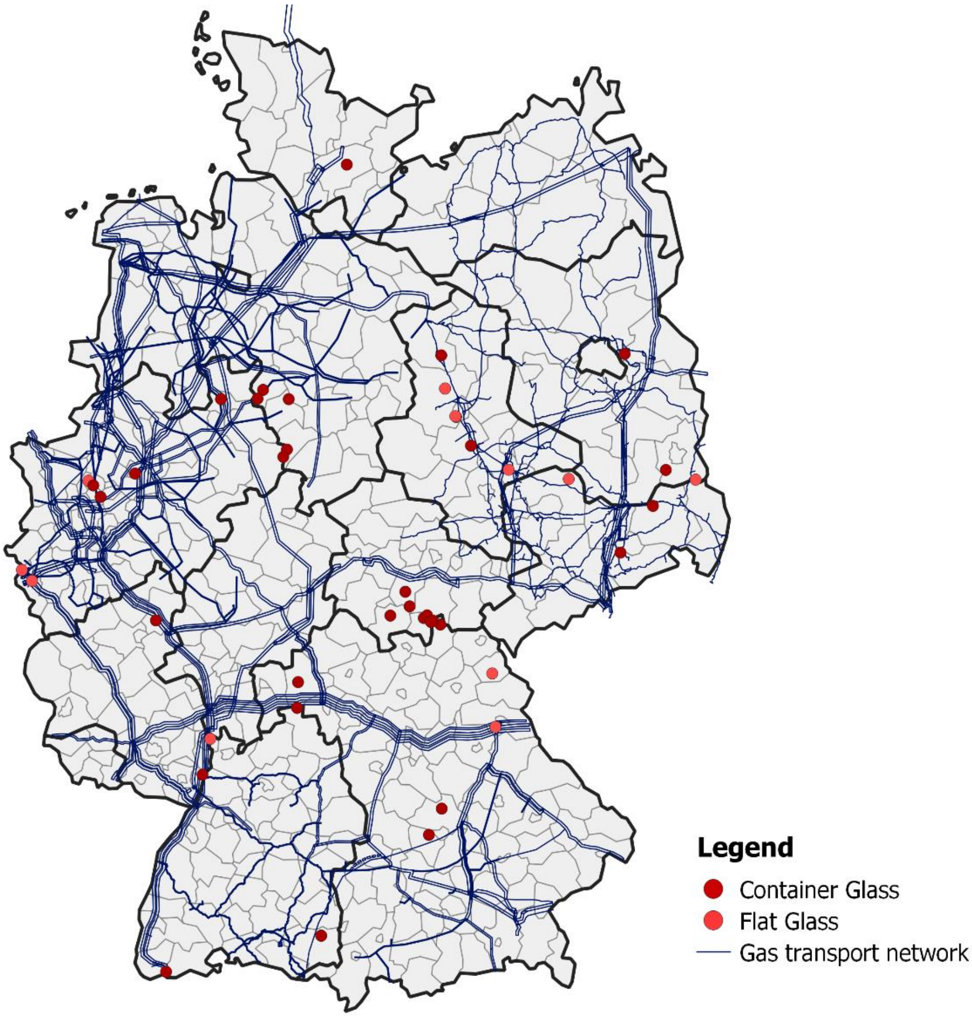

Figure 6. Glass production sites in combination with the current gas transportation network. Dark red circles are production sites for container glass and light red circles are production sites for flat glass. Based on [26,34] and updated from [27].

The use of hydrogen in the production of glass and ceramics is not foreseen in the long-term and climate scenarios considered. In the electricity pathway, the majority of the processes are electrified (14 TWh by 2050) and a smaller portion are supplied by heating networks (1 TWh by 2050) [3]. The natural gas demand will be phased out slowly, with a 20% decrease by 2030 and a 70% decrease by 2040 in comparison to 2019 [3]. In contrast, the PtG/PtL pathway shows only a slight decrease of 2% in methane demand by 2050 compared to 2019, resulting from processes switching from natural gas to synthetic methane [3].

In conclusion, depending on the glass type, some production sites are supplied by the gas transportation network, such as flat-glass production sites, and other production sites are supplied by the gas distribution network, including more than 40% of container-glass production sites. For the production of container glass in particular, higher electrification levels, even for large melting tanks, have been investigated, and in combination with the electricity pathway—and even the slight decrease in the gas pathway (PtG/PtL)—of the long-term and climate scenarios, decreasing gas demand seems likely. Consequently, in regions dominated by the glass and ceramics industry, the decreasing gas demand will affect the DNOs.

4.5. Mineral Processing

The mineral processing industry had an overall natural gas demand of 12.9 TWh in 2019 [21], of which 37% was related to cement production [1]. Overall, 104 lime and cement production sites exist in Germany [26]. Some of these cement production sites include the production of clinker, which has the highest fossil fuel demand in cement production. The other production sites are of less importance for this paper due to their higher share of electricity demand and almost no thermal energy demand [32,55].

Cement production sites are often located in the countryside close to limestone deposits [32,55]. Figure 7 illustrates that about 8 of the 29 cement production sites including clinker production are located further away from the gas transportation network; hence, they are connected to the gas distribution network. Nonetheless, the majority of the production sites (72%) seem to be supplied by the gas transportation network.

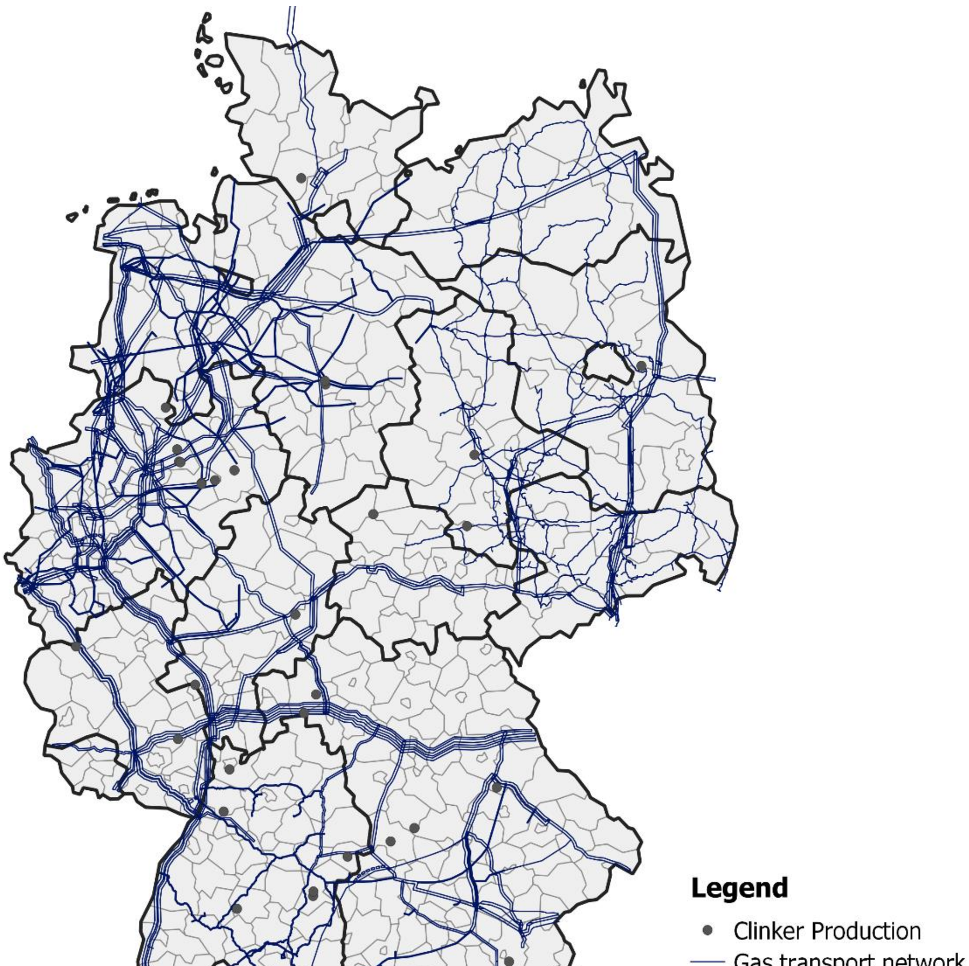

Figure 7. Cement production sites including clinker production in combination with the current gas transportation network. Based on [26,34] and updated from [27].

In the cement industry, around 88% of the total energy demand is for the production of thermal energy for the drying process and the firing of rotary furnaces, with process temperatures of up to 1,450 °C for clinker production [55]. Alternative fuels, such as used tires, used oil, animal meal and plastic waste, are generally used to fuel these processes, accounting for a share of 67% of total fuel consumption [56]. Natural gas is only used in a smaller amount with a share of 1% [55,56]. To increase efficiency, the waste heat from furnaces is used as heat in the drying process, decreasing the fuel demand [57]. Substituting clinker with other components, such as slag sand from the steel industry or fly ash from the conversion sector, can decrease clinker production and, thus, the fuel demand [55].

To further decarbonize the production of cement, the drying process can be electrified (TRLs 4–5) or CO_2-neutral fuels, such as biomass (TRLs 7–9) or synthetic methane (TRLs 5–7), can be applied [32,51]. The electrification of rotary furnaces has been investigated in pilot projects, such as CemZero [58], but is not currently considered an option [44,51]. This perspective is supported by the authors of [53], who do not expect a fundamental change in current processes. Further, process-related emissions entail the need for CCS or CCU for a highly decarbonized cement industry (TRLs 3–6) and, hence, the necessity of a separate CO_2 infrastructure [32].

A need for a separate CO_2 infrastructure is also seen in the PtG/PtL pathway of the long-term and climate scenarios combined with a switch to synthetic methane, which would lead to an increase in methane demand to 36 TWh by 2050 [3]. This increase will start slow with only a 2 TWh greater methane demand by 2030 and speed up by 2040 with a methane demand of 22 TWh [3]. Even the electricity pathway shows an increase to 17 TWh by 2030 and a fast decrease of 40% between 2030 and 2040, leading to the phasing out of methane demand by 2050 [3].

To sum up, alternative fuels seem to play an important role in the cement industry. The future gas demand seems likely to be constant or might increase, switching from natural gas to synthetic methane. Considering that more than one quarter of production sites tend to be supplied by the gas distribution network, increasing gas demand could have an effect on the network development.

5. Discussion and Conclusions

This paper contributes to the literature by investigating the gas network level at which methane is supplied to industry branches and how the methane demand may change in a future decarbonized energy system in the industry branches chosen as a case study for Germany. We herewith answer the question: can industry keep gas distribution networks alive? In addressing this question, the paper pointed out that clear, separate definitions of the gas transportation and distribution networks regarding the amount of gas transported do not exist, since the gas distribution network supplies end consumers regardless of the pressure level or diameter of the pipelines. For this reason, we explored the main industry branches that currently consume methane more deeply.

The industry branches relating to basic chemicals, iron and steel, food and tobacco, pulp and paper, glass and ceramics and mineral processing were identified as the main consumers of natural gas in the German industry sector in 2019. By calculating their average natural gas demand per production site, we were able to provide a first estimate of their consumer category using the categories provided in [5] and, hence, their network connection level.

The assessment showed that most companies in the basic chemicals industry branch are connected to the gas transportation network, whereas most industrial consumers from the food and tobacco and the iron and steel industries are connected to the gas distribution network. This finding contradicts the assumption made in [16], where the authors assume that the steel industry is supplied by the gas transportation network. For the pulp and paper, glass and mineral processing industry branches, categorization at one network level is difficult. The locations of the pulp and paper industry sites show that about two thirds of the production sites are connected to the gas transportation network and one third to the gas distribution network. In the glass industry, the network connection level depends on the glass type. While the majority of flat-glass production sites seem to be supplied by the gas transportation network, nearly half of the container-glass production sites are supplied by the gas distribution network. Lastly, in the mineral processing industry, with a focus on cement production, the majority of the production sites seem to be connected to the gas transportation network and one quarter of them are supplied by the gas distribution network. In total, almost one third of the industrial production sites analyzed are supplied by the gas distribution network. In comparison to the assumption in [14], which suggested that 35% of industrial gas demand is supplied by the gas distribution network, our analysis derived a slight lower share (for a summary, see Table 4).

Table 4. Summary of findings (produced by the authors).

Industry	Basic Chemicals	Iron and Steel	Food and Tobacco	Pulp and Paper	Glass/Ceramics	Mineral Processing
Average natural gas demand per production site in 2019 (TWh/a)	1,758.6	638.0	6.0	113.2	40.2	123.9
Estimated proportion of industrial production sites connected to distribution grid	~0%	~70%	~100%	30%	~40%	28%
Timeline for complete switch to alternatives to natural gas [3]	n/a	2030–2050	2020–2050	2020–2050	2020–2050	2030–2050

New business models for the gas distribution network will be necessary if the demand decreases, as outlined in the PtG/PtL scenario chosen, in the food and tobacco, pulp and paper and glass and ceramics industries. Taking the decreasing gas demand in the building sector and the rather low gas demand in the transportation sector into account, there will be industrial regions in which the gas distribution network will need to be decommissioned due to its unfeasible economic operation. Hence, the industry sector cannot prevent the decommissioning of the gas distribution network in some regions.

Comparing the competing technologies in the industry branches, it can be seen that not only the electricity network (i.e., using heat pumps or electrolysis) but also the heating network (using waste heat) are adequate alternatives in some industry branches, such as the glass industry. However, new infrastructures for hydrogen or CO_2 transportation are also alternative usage options for the gas network, leading to new opportunities for the distribution network operators. In particular, the ramp-up of hydrogen infrastructure, with the steel industry as first mover as early as the period between 2030 and 2040, could offer new opportunities for local distribution network operators. Consequently, certain distribution network operators should also be included in the strategy for the building up of the German hydrogen infrastructure.

This paper provides preliminary insights into the network supply of the different industry branches. For more detailed insights, an analysis that is not solely based on the location of the gas transportation network and the industrial production sites, taking into account the heterogeneity within the different industry branches, would be necessary. Therefore, every production site needs to be investigated separately to find out the definite network levels.

Nonetheless, the preliminary estimations provided by this paper will help to further investigate the regions in which the decommissioning of the gas distribution network is economically feasible. Hence, a detailed cost assessment, taking into account the regulatory framework, of the distribution network operators in the regions with industry supplied by the gas distribution network can be conducted as a next step.

Furthermore, even though this paper focused on Germany as a case study, the challenge of identifying the network levels at which the different industry branches are supplied exists in other countries too. This paper focused on Germany because of the high importance of natural gas in the German energy mix and the large numbers of actors, gas consumers and gas network operators compared to other European countries. Nonetheless, the methods applied to determine the network connection levels and to gain more insight into the future role of the gas distribution network can be applied to any other country in the EU. The Fraunhofer ISI Industrial Site Database already includes the locations of 5,440 industry sites in the EU, and the EU-wide gas transportation network is provided by ENTSOG.

Lastly, the attack of Ukraine by Russia and the consequent energy crisis in Europe have changed the situation dramatically. With the greater ambition to decrease the gas demand in Europe, many industries will try to change their production processes even sooner. Hence, the earlier values in the estimated timelines could be even more realistic.

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