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THE IMPORTANCE OF GAS INFRASTRUCTURE FOR THE GERMAN ENERGIEWENDE

Thanks to sector coupling in Germany, more and more consumer sectors such as heat and transport will be switched over to entirely renewable sources of energy in the long term. A model-based analysis of the system costs across all stages of the energy supply chain shows that the existing gas infrastructure in Germany is able to make a significant contribution to achieving a comprehensive energy transition ("Energiewende") without great expense. Preservation of the gas networks, combined with the use of "green gas" as a further final energy medium alongside electricity, will result in significantly lower overall costs than the universal electrification of all end-use applications, and it can also help to overcome customer acceptance problems.

This paper is based on a study on the German energy market carried out (originally in German) by Frontier Economics, IAEW, 4Management and EMCEL on behalf of the Association of German Gas Transmission System Operators (FNB Gas e.V.).[1]

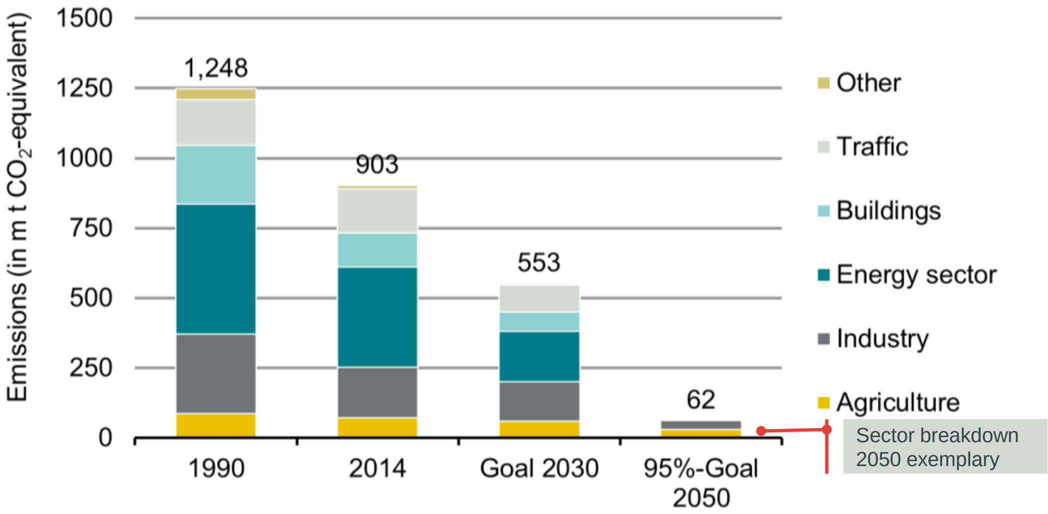
Green gas as an alternative to electricity transport

Germany has set itself ambitious climate protection targets: by 2050, greenhouse gas emissions are to be reduced by 80 to 95 per cent compared to 1990. Assuming a reduction scenario of 95 per cent, a maximum of 62 million tonnes of CO2-equivalent emissions shall be allowed in 2050. Since a proportion of present-day emissions are practically unavoidable in the agricultural and industrial sectors (without significant loss of benefits to society), the energy, transport and heat generation industries must be decarbonised almost completely, with industrial emissions needing to be substantially reduced (**Figure** 1).

As well as avoiding energy consumption ("efficiency first") and making direct use of renewable energies such as biomass or solar energy, the potential for which is however limited in Germany, a process known as "sector coupling" is to be primarily used to achieve this reduction of emissions in other sectors. Using this process, the sectors which have previously been dominated by fossil fuels, such as heat (natural gas and heating oil) and transport (primarily mineral oil), will be switched over to using renewable electricity.

[1] Frontier Economics, IAEW, 4M and EMCEL (2017), Der Wert von Gasinfrastruktur für die Energiewende in Deutschland – Eine modellbasierte Analyse, study on behalf of FNB Gas e.V, October 2017.

Figure 1 Development of CO2 emissions by 2050 according to the German Climate Action Plan 2050



Source: *Frontier Economics based on information from the Federal Environmental Agency: National greenhouse gas inventory 2017, final status 04/2017 and the Federal Ministry for the Environment, Nature Conservation, Construction and Reactor Safety (2016): 2050 Climate Plan, climate policy principles and goals of the Federal Government.*

While the public debate among experts is increasingly reaching consensus over the fact that this form of sector coupling is the proper and necessary solution for the achievement of ambitious climate goals, the question remains over which energy transport infrastructure will be used in the future to establish the connection between renewably generated electricity and energy consumers, and in particular what role the gas infrastructure will play going forward.

Today, the annual consumption of gas in Germany – which is dominated mainly by natural gas and a share of biogas – is just under 600 TWh, equivalent to around 24 per cent of the country's overall final energy requirements. In the heat sector, the gas ratio accounts for as much as 45 per cent. Germany has an extensive gas transport, storage and distribution infrastructure in place with over 500,000 kilometres of pipelines.

This, therefore, raises the question of whether and how the gas infrastructure can contribute to the energy transition, given the strict decarbonisation goals which are inconsistent with the ongoing use of fossil natural gas over the long run.

One option would be to use the infrastructure to transport “green gas” in the future, i.e. climate-neutral gas obtained from biogas or generated synthetically from renewable electricity in the form of hydrogen or methane.[2] Given the conversion stages required for this (e.g. power-to-gas) and the impacts on end-use applications (e.g. retention of gas boilers compared to electricity-based heating systems), the question arises of how the costs of this type of parallel operation can be evaluated in a future energy system.

[2] Cf. Bothe, Janssen, Riechmann, “Future of the gas industry - energy medium instead of energy source?”, in: Energiewirtschaftliche Tagesfragen, 3/2017.

To this end, as part of a system costs evaluation that takes account of all elements of the supply chain, in the rest of this paper we analyse what cost impact the long-term continued use of the gas infrastructure for the transport of "green gas" would have on the energy system. We focus the analysis on year 2050.

2050 energy systems with or without gas networks

To do this, we analysed two scenarios for 2050 (**Figure 2**), which incorporated all of the consumer sectors (i.e. in particular also heat and transport as the largest sectors for final energy consumption):

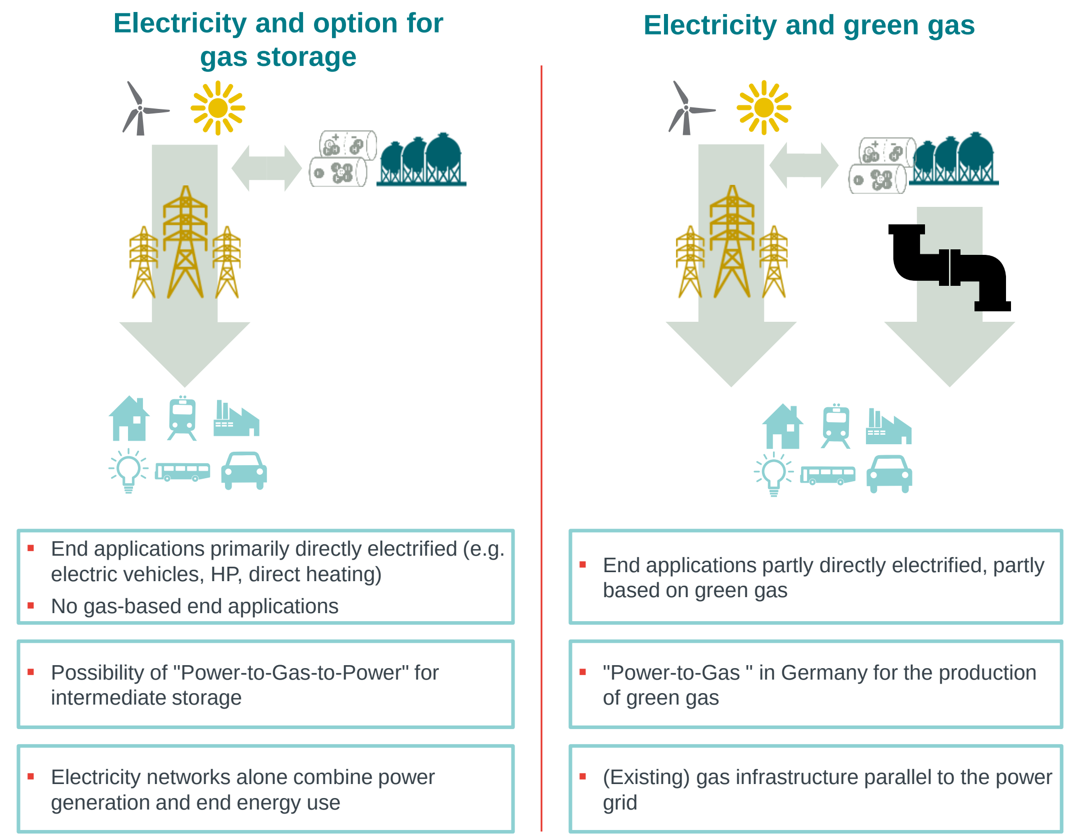
- **"Electricity and option of gas storage"** – Consumers primarily use electrical applications such as heat pumps and electric cars ("direct electrification"). There is also the technical possibility to temporarily store electricity in the form of gas and to feed it back to gas-fired power plants ("power-to-gas-to-power" or PtGtP). Energy transport from energy generation to final energy use is exclusively based on power networks, however. Accordingly, gas transport and distribution networks – unlike gas storage systems – are no longer required in this scenario and will be decommissioned.
- **"Electricity and green gas"** – In this scenario, some end-user applications remain gas-based and will in future use green gas, which is generated synthetically in German power-to-gas (PtG) plants based on renewably generated electricity ("indirect electrification").[3] Accordingly, in parallel to the electricity network, the existing gas infrastructure (including gas transport and distribution networks) will continue to be used for energy transport.

In order to ensure comparability, all scenarios assume that the Federal Government's ambitious climate goals are met in 2050, with a 95 per cent reduction in greenhouse gas emissions as compared to 1990.

Since the burning of hydrogen does not produce any CO2 emissions whatsoever, green gas is always climate-neutral. Even when synthetic methane is used, the volume of CO2 released is exactly the same as that taken from the environment during the production of synthetic gas.

[3] Green gas also incorporates biogas, however, for simplification purposes this is abstracted in the calculations.

Figure 2 Summary of the scenarios reviewed



Source: Frontier Economcis

Systemic analysis of costs over the entire supply chain from production to consumption

In order to compare the system costs in both scenarios, we used the following procedures (**Figure 3**):

- **Identical end-use requirements** – To ensure an adequate comparison of the scenarios, we assumed identical end usage of energy in all scenarios. This means that, in all scenarios, the area heated or transport kilometres travelled are the same. General consumption trends anticipated by 2050 are based on third-party studies. From 2015 to 2050, the energy demand for heating buildings and supplying hot water reduces by 34 per cent through efficiency measures and demographics in all scenarios (based on Fraunhofer (2015)[4]), while the number of persons or tonne-kilometres in transport, for example, increase (UBA (2016)).[5]
- **Scenario-specific final energy requirements** – Since different degrees of efficacy are associated with different technologies at the end-use application stage, we derived corresponding scenario-specific final energy demands

4 Cf. Fraunhofer (2015). Interaction of RE electricity. Heat and transport. Analysis of the interaction between the sectors of electricity, heat/cooling and transport in Germany in relation to the growing proportion of fluctuating renewable energies in the electricity sector, taking account of European development.

5 Cf. UBA (2016). Drafting of an expert strategy to provide energy for transport by 2050.

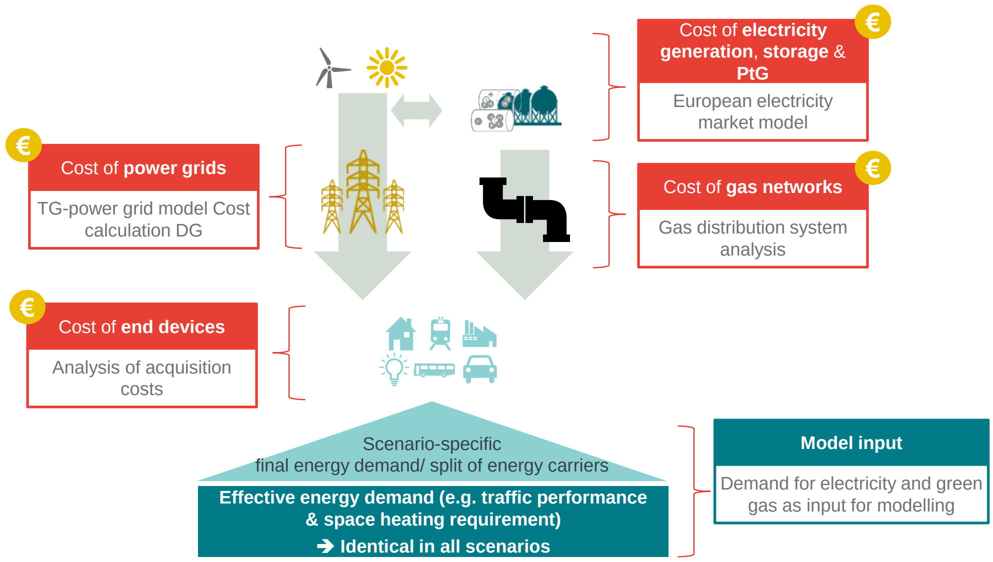
based on identical end-use requirements. In the “Electricity and option of gas storage” scenario, an electricity demand of 965 TWh needs to be covered for end-use applications by 2050 (no gas requirements). In the “Electricity and green gas” scenario, however, only 468 TWh of electricity are required for the final energy demand, in turn there is still demand of 645 TWh for green gas.

This final energy demand must be covered with suitable electricity generation and conversion technologies (for synthetic gas) and be provided through the relevant network infrastructures. To do this, we determined the ideal design of the infrastructure in each scenario using system-wide models and then identified the resulting system costs along the supply chain:

- **Costs of end-use applications –** At this stage of the supply chain, the costs of the end-use applications for final energy use are taken into account. In this case, we looked in particular at the differences between the scenarios in costs to customers of purchasing heat applications and vehicles.[6]
- **Costs of electricity networks –** Using network models, the different expansion and maintenance requirements on transport and distribution networks for electricity are estimated in both scenarios and the corresponding cost implications were determined.
- **Costs of gas networks –** The costs of adapting, expanding and maintaining the transport and distribution networks for green gas are taken into account in the scenarios, as well as the costs for potentially dismantling any existing gas infrastructure no longer in use.
- **Costs of electricity generation and conversion –** For this, we use a comprehensive electricity market simulation to model the costs of generating/storing electricity as well as the costs of converting the electricity to gas in power-to-gas plants.

[6] The assumptions regarding future procurement costs are based on third-party studies, including Fraunhofer (2015). Interaction of RE electricity. Heat and transport. Analysis of the interaction between the sectors of electricity, heat/cooling and transport in Germany in relation to the growing proportion of fluctuating renewable energies in the electricity sector, taking account of European development; Fraunhofer (2015). What does the energy revolution cost – ways to transform the German energy system by 2050 and UBA (2016). Drafting of an expert strategy to provide energy for transport by 2050.

Figure 3 Methods: systemic analysis of costs over the entire supply chain from generation to the consumer



Source: Frontier Economics

Green gas for long-term storage is essential for a future energy system

Firstly, the analyses show that an “all-electric” world would be prohibitively expensive without the use of gas storage systems, at least for seasonal storage of renewable electricity: this is evident in the results from the integrated investment and dispatch electricity market model, in which the level of investment in systems to generate electricity from renewable energies, for example, in power-to-gas plants and in gas-fired power plants for reconversion, is simultaneously optimised. As a result, in the context of optimising the “Electricity and option of gas storage” scenario by 2050, power-to-gas plants with an overall capacity of 134 GW_{el} are installed. This is despite the fact that consumers in this scenario exclusively use electricity-based end-use applications, meaning there are no gas networks to supply end-use consumption directly. For reconversion from gas to electricity, gas-fired power plants with an overall output of 141 GW are installed.

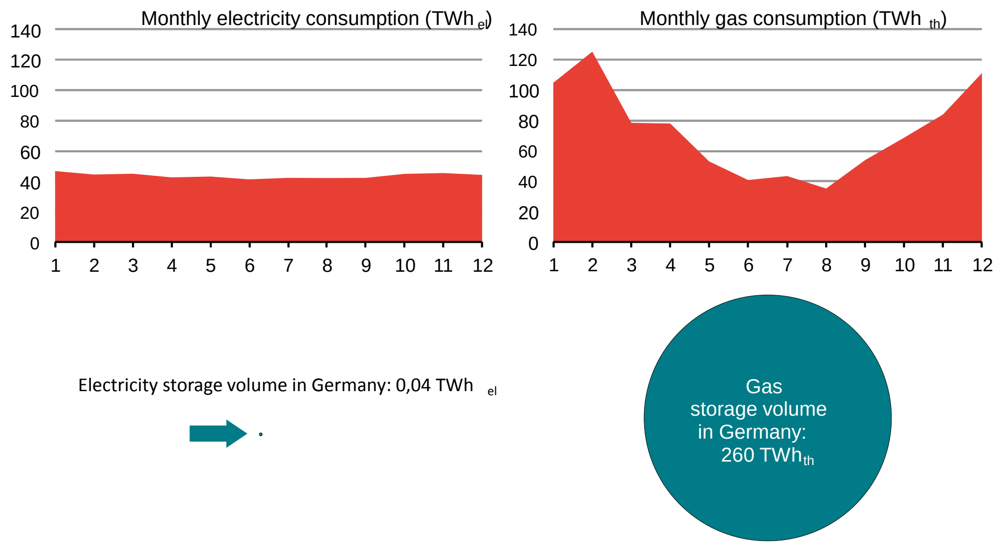
This result shows that it is economically more favourable to balance intermittent renewable electricity supply and seasonal electricity demand by temporarily storing gas on a substantial scale and accepting the resulting conversion losses, rather than completely removing seasonal storage and investing in more renewable energy plants or electricity storage systems, for example, pump storage or batteries.

This model result is intuitively simple to understand:

- Tremendous challenges are presented by the future high seasonality of electricity demand with electrified heat provision and the dependency of that electricity's availability on the wind and sun.

- Electricity storage devices such as pumped storage power plants or batteries are only able to store energy for short periods and in small quantities. For example, the current storage volume of all electricity storage systems (including all pumped storage) in Germany is just 0.4 $TWh_{el.}$
- By comparison, the gas sector is designed to cope with significant seasonality: the average consumption of gas in February, for example, is more than three times higher than in August. To overcome this seasonal consumption – with relatively constant supply availability – Germany has gas storage volume of around 260 TWhth which, even after taking account of potential conversion losses, is several magnitudes higher (**Figure 4**).

Figure 4 Comparison of monthly demand in the electricity and gas sector and existing storage capacities (as of 2015)



Source: Frontier Economics

Therefore, an “all-electric” world without the use of gas storage systems - at least for seasonal storage and for bridging cold, dark periods with low wind supply - is prohibitively expensive and unrealistic, as other studies such as Enervis (2017)[7] or Energy Brainpool (2017)[8] have recently demonstrated. Gas storage systems for seasonal storage are, therefore, definitely required in a future energy system based on very high ratios of renewable energies, as highlighted by the Federal Ministry of Economics and Energy (BMWi) in its discussion paper entitled “Electricity 2030”.[9]

7 Enervis (2017). Climate protection through sector coupling: Options. Scenarios. Costs. Study by Enervis energy advisors GmbH on behalf of the DEA. EWE. Gascasde. Open Grid Europe. Shell. Statoil. Thüga and VNG.

8 Energy Brainpool (2017). Cold dark, calm periods. Robustness of the electricity system during extreme weather. Study on behalf of Greenpeace Energy EG.

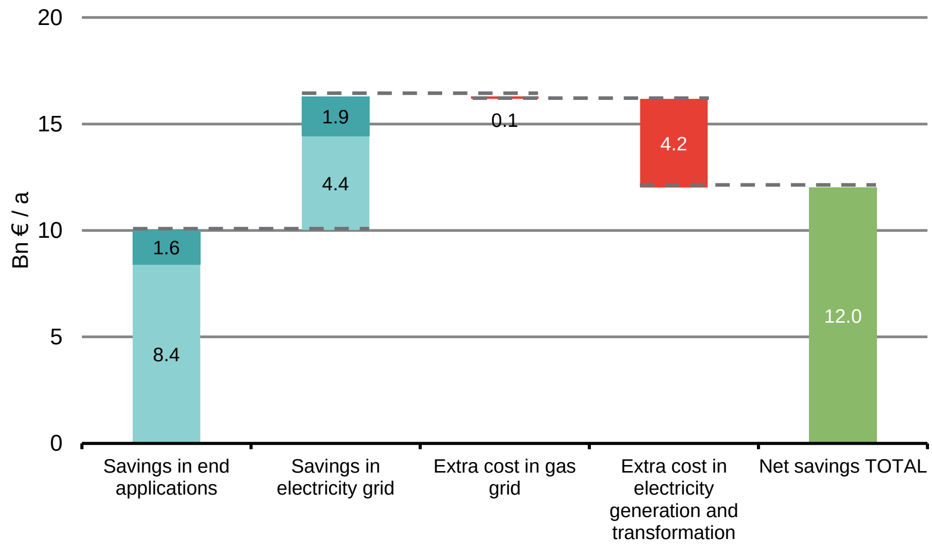
9 BMWi (2017). Results paper Electricity 2030 – Long-term trends – Tasks for the next few years, page 19: ‘Conventional technologies such as pump storage power plants and batteries are only able to store electricity for a few hours. They are unsuitable for bridging a “dark, calm spell” of several days in winter. New technologies such as power-to-gas with reconversion in gas-fired power plants could serve as long-term storage systems, however, the high conversion losses make them extremely expensive. Their use is only practical with significantly higher ratios of renewable energies.’ (BMWi (2017), page 19)

Use of green gas by end-consumers significantly reduces system costs

Furthermore, comparing the two scenarios reveals that the continued use of the gas transport and distribution networks to supply end-customers with green gas ("Electricity and green gas" scenario) offers further cost benefits compared to a world in which the gas networks are no longer used ("Electricity and option of gas storage" scenario).

By 2050, the overall savings will amount to around EUR 12 billion per year (real in 2015 values) in terms of the annualised system costs. These savings also reflect avoided investments in electricity networks and end-use application devices of around EUR 268 billion by the year 2050 (without discounting future costs).

Figure 5 Annual savings on system costs in the "Electricity and green gas" scenario compared to the "Electricity and option of gas storage" scenario (around 2050)



Source: Simulation results – Frontier Economics, IAEW, 4M, EMCEL

Note: The per annum costs are shown in EUR for the year 20502015

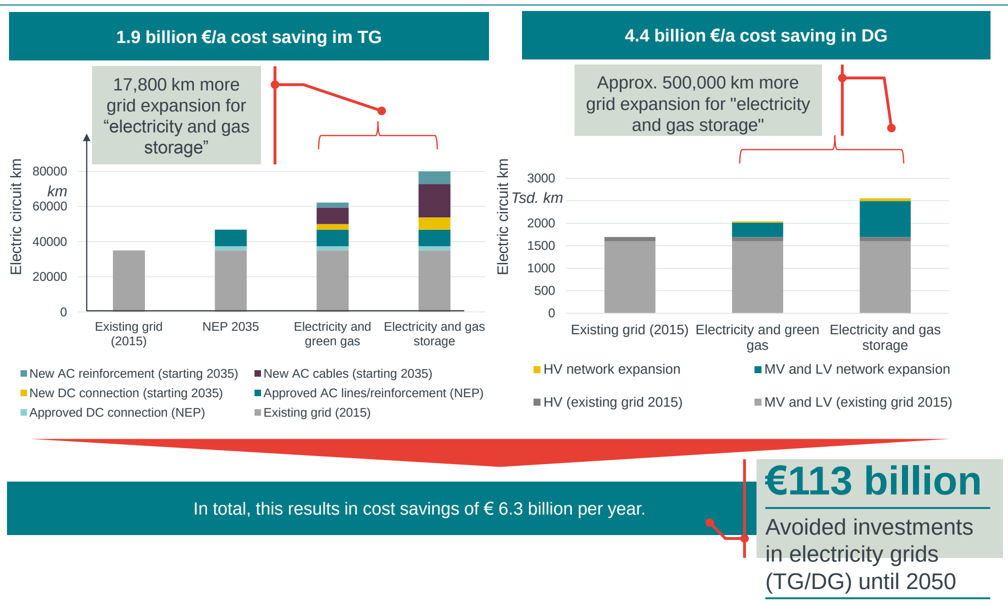
Figure 5 illustrates that the overall cost savings of using the gas network are made up of:

- Lower costs for gas-based end-use applications (EUR 10 billion per year by 2050), especially in the heating sector (EUR 8.4 billion per year): since in the "Electricity and green gas" scenario, gas boilers can continue to be used in some cases (e.g. in existing buildings in particular) instead of more capital-intensive heat pumps.
- Savings from significantly lower electricity network expansion requirements (EUR 6.3 billion per year by 2050) as a consequence of using the gas network: the need to expand the electricity transmission network reduces by around 40 per cent, and the distribution network by as much as 60 per cent (**Figure 6**).

These savings of EUR 16.3 billion in total significantly over-compensate the additional costs that are generated elsewhere in the system:

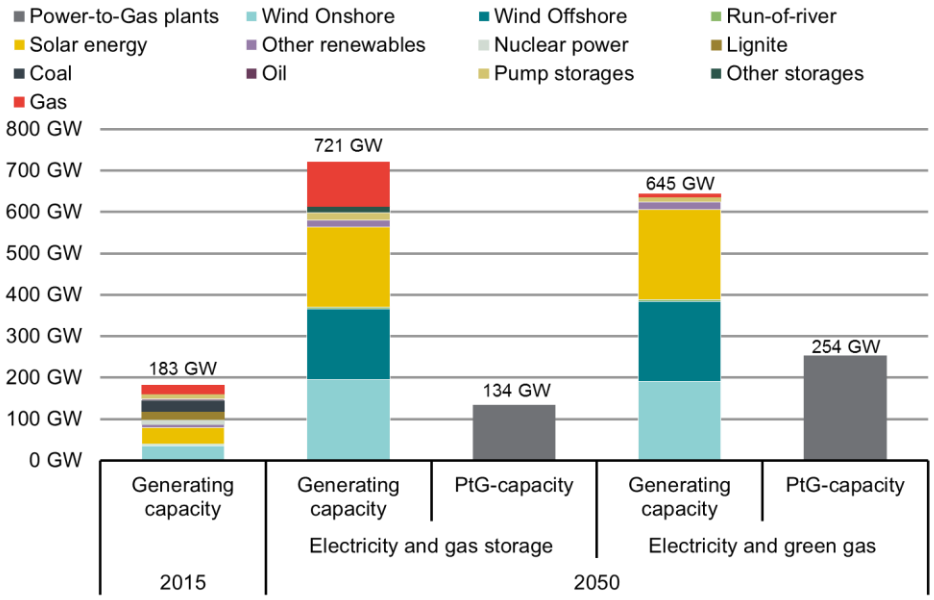
- The annual additional costs for the retention and partial conversion of gas networks which, compared to decommissioning costs if the gas network were no longer used, only amount to EUR 0.1 billion by around 2050.
- The costs for additional electricity generation and power-to-gas plants required due to conversion losses (EUR 4.2 billion per year by 2050) are based largely on variable costs (in particular for the recovery of non-fossil CO_2 for methanisation). Since the higher demand of PtG plants in the "Electricity and green gas" scenario is offset by a reduced demand for gas-fired power plants to cover dark, calm periods (**Figure 7**), the investment costs do not differ substantially between both scenarios.

Figure 6 Comparison of costs and electricity circuit kilometres in the "Electricity and green gas" and "Electricity with the option of gas storage" scenarios



Source: Simulation results – IAEW

Figure 7 Comparison of the installed electricity generation and PtG capacities



Source: Simulation results – Frontier

Gas infrastructure increases acceptance of the energy transition

Beyond pure system costs, using the gas infrastructure can also support the energy transition in other areas. An acceptance problem in relation to the energy transition already exists and will continue to grow significantly over time. Although the expansion of renewable energies is still fundamentally perceived as largely positive, the situation is different when it comes to agreeing to individual measures at a local level (known as “Not-In-My-Backyard”, NIMBY).

There is already considerable resistance to the expansion of electricity networks in Germany, for example, which has led to severe delays in their expansion. Further, the German public has not yet registered that electricity distribution networks need to be expanded substantially in the next few years.

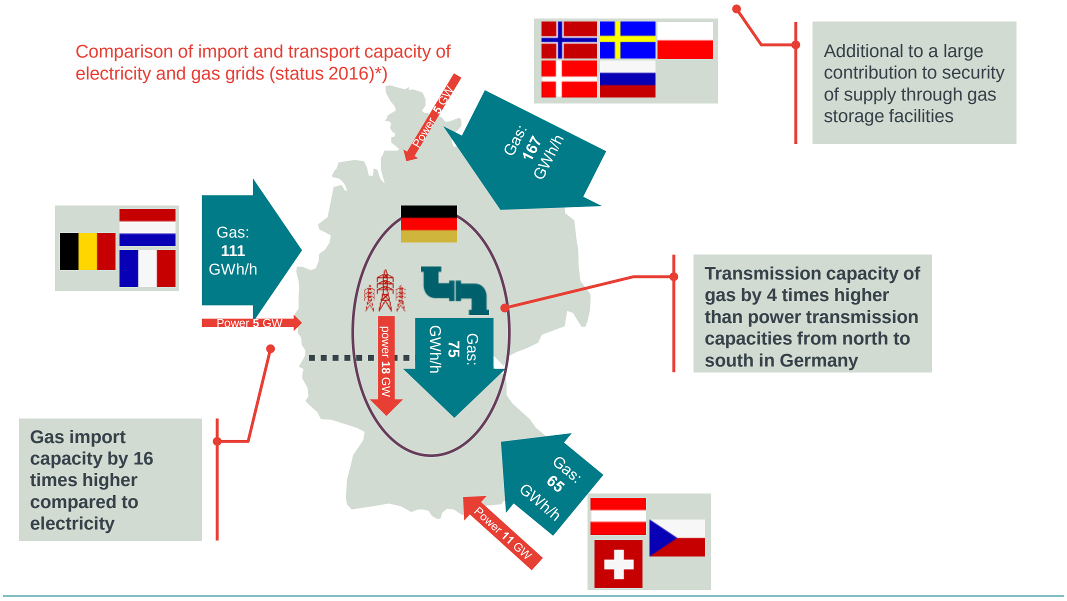
The use of the existing gas transport infrastructure represents an alternative to expanding the electricity network. Our electricity network models show that using gas networks reduces the need to expand the electricity transmission network in Germany by around 40 per cent, and by as much as 60 per cent for the distribution network. Since gas networks already exist and have been built underground, they can contribute significantly to the acceptance of the energy transition.

In addition to the networks, there are also major acceptance problems on the generation side, especially because only a fraction of the electricity generation capacity required for a comprehensive energy transition has actually been built thus far. At least the analyses here show that using the gas infrastructure does not entail any significant disadvantages: despite the resulting conversion losses, the installed capacity is virtually the same thanks to improved utilisation via gas storages.

It should be considered an advantage, however, that the gas infrastructure in Germany is closely integrated into a pan-European network structure (**Figure 8**). This structure allows energy to be transported over long distances and therefore facilitates access to the international gas transport network and consequently to sources of green gas in other countries. In addition to the obvious benefits in terms of security of supply, other supply sources of green gas with much lower generation costs can be accessed for the German market, reducing the need to generate renewable energies in a densely populated country such as Germany. Our analysis has not even considered cross-border green gas options (in order to ensure comparability with electricity-only solutions), but in practice these could be of major significance in the future for realising the energy transition.

We must also not forget end users: their consent and acceptance is of major importance for the forthcoming conversions of end-user devices to achieve the energy transition. The variety of technology options available can increase by maintaining gas as an energy medium. Furthermore, the option of continuing to use established technologies (e.g. gas boilers) allows potential switching hurdles to be avoided.

Figure 8 Comparison of import and transport capacity on electricity and gas networks (as of 2016)



Source: Frontier Economics based on Entso-E, Entso-G and information from transmission network operators.

Summary: Keep a mix of energy infrastructure – with gas infrastructure to play a vital role

In summary, our analysis for Germany shows that

- Gas storage systems will still be essential for long-term storage, even in the event of a virtually total electrification of end-use applications, due to a lack of electricity storage technologies.
- Using gas networks to supply gas-based end-use applications, for example, in the heat, transport or industrial sectors, can significantly reduce system costs.
- Using existing gas networks and established gas-based end-use applications encourages acceptance of the energy transition.
- Access to cross-border highly interconnected gas infrastructure strengthens the security of energy supply and potentially opens up even cheaper sources of renewable energy.

Based on these results, we conclude that

- Comparisons of different energy solutions must always be done systemically along the entire supply chain. Partial analyses, for example, with a focus on the level of fuel efficiency, can lead to false estimates due to the fact that feedback effects, such as that of power-to-gas on electricity network expansion or investments in consumer devices, are neglected.
- In the context of growing sector coupling, infrastructure planning must take place on an integrated basis. Isolated planning, for example, of the electricity networks, harbours the danger of substantial additional costs since the contribution of alternative energy sources (e.g. green gas) is not taken into account.
- The future framework conditions must enable fair competition between technologies and let individual technologies demonstrate their advantages. For example, a premature ban on individual technologies such as gas boilers or combustion engines can result in lock-in effects and additional costs, since these technologies may contribute in future to low-cost decarbonisation when based on alternative fuels.