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The Role of Natural Gas, Renewables and Energy Efficiency in Decarbonisation in Germany:

The need to complement renewables by decarbonized gas to meet the Paris targets

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Preface

As the European region continues to prioritise the decarbonisation of its energy system, Germany provides a fascinating case study of the potential gains and pitfalls from the introduction of renewables into the energy mix, in particular with relation to gas. In this extensive review of German energy policy and its impact over the past few years, Ralf Dickel analyses the reasons why gas has, to date, failed to make a strong case for a long-term role in the country. He argues that the gas industry has failed to make the important distinction between a carbon-free energy sector and an all-renewable energy sector and has so far not addressed decarbonising natural gas as a necessary complement and competitor to renewables to meet the targets of the Paris Agreement in time.

He firstly reviews the implications of the Paris Agreement on Climate Change for renewables and gas before turning to the question of German decarbonisation policy and assesses the roles given to energy efficiency and renewable energy in achieving emissions objectives. He notes that although targets for renewables are sure to be met, Germany has singularly failed to meet emissions targets, and argues that the failure to adequately incorporate gas into the energy mix (largely in place of coal) is a key reason for this.

He then reviews the potential roles for gas across the various energy consuming sectors in Germany. He considers the potential substitution of natural gas with biogas, before reviewing the heat sector, power generation (where the interaction with renewables is at its most intense), industry and transport. In conclusion, he questions the logic of German energy policy, as while it will clearly achieve some of its goals, including the phase out of nuclear, it will manifestly miss the key target of reducing carbon emissions. As such, the paper provides some stark lessons for European and individual country policy makers, as they strive to find the correct balance between political and economic reality and the increasing need to meet Green House Gas targets in the global energy economy.

James Henderson

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Ralf Dickel, April 2018

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Introduction

This paper looks at the implications of the 2015 Paris Agreement for renewables, energy efficiency and natural gas and draws conclusions on the limitations of renewables for meeting national and international climate targets, illustrated by the past and present German renewable-focused approach. It discusses the need to complement an all-electric renewable approach with the important contribution decarbonized natural gas can make to meet the decarbonisation targets of the Paris Agreement within the time frame given by it. Finally, it illustrates the overlap of EU decarbonisation and German renewable policy and how this hinders short term fuel switching to natural gas and possible remedies. Throughout the paper "gas", unless otherwise specified, should be taken to mean "natural gas".

Executive Summary

The German government, which claims an international pioneer role in decarbonisation, rather follows a renewables policy, substituting the instrument for the target. While meeting its own renewables targets for 2020 (35% renewables in power production), Germany will only reduce its GHG emissions by 30% instead of the 40% target for 2020.

Renewable technology will be essential to achieve a decarbonised world. However, the analysis of the German experience by this paper suggests that renewables alone will not make the necessary contribution in time to meet the German contribution to the target of the Paris Agreement (PA), to keep the global temperature increase within 2 degrees Celsius, equivalent to staying within the carbon budget of 1,000 Gt of CO_2 left to be emitted after 2015. The deployment of more renewables and overcoming the problems linked to an all-electric renewables world both on the supply and on the demand side will be too slow, while the possibility of staying within the carbon budget is fading away. If an all renewable energy world does not work for Germany in time, it is also unlikely to work on a global scale.

As a consequence, keeping within the carbon budget requires mandatory development of decarbonised natural gas (and other de-carbonised hydrocarbons) as a GHG free complement and competitor to electric renewables. Conceptually it is essential to make the distinction between a carbon-free energy sector (which can include decarbonised, but admittedly fossil fuels) and a sustainable energy sector (which will have to be all renewable). An entirely sustainable energy sector is not necessary to achieve the targets of the PA and can follow, when the hydrocarbon resources lending themselves to decarbonisation have been used up. Unfortunately, it was not only German politicians who fell into the trap of equating "carbon-free" with "renewable", but implicitly also the gas industry with its narrative of highly flexible gas-fired power plants as a complement to intermittent renewable power generation. Decarbonising natural gas is possible by the well-known reforming process, which produces hydrogen (and CO_2 to be reinjected e.g. into producing reservoirs) and would allow continued use of the existing infrastructure and equipment based on continued use of a large share of natural gas reserves. It could also be used in fuel cells as a carbon-free alternative to the electric plug-in car. In these ways the value of gas resources can be kept.

Instead of natural gas being a bridge fuel (having least carbon intensity) decarbonized natural gas, mainly in the form of hydrogen, must become part of the carbon free energy world.

While fostering decarbonised gas is mandatory in the long run, it is also important to optimise de-carbonisation efforts for the immediate future. Here the present German policy, focused on a renewables policy, comes with a substantial overlap with the EU emission trading regime, reinforcing the problems of the low price of the emission trading rights (EUA) due to oversupply. It is not only that the renewables instrument does not produce the decarbonization results aimed at , it also creates conflicts with other policy targets such as reliability of power supply and has repercussions far beyond the German power grid. German policy makers should consider analytical and practical instruments that directly address decarbonization, which may allow the harvesting of the benefits of fuels switching for de-carbonisation, like a carbon tax or a carbon floor in line with the UK example.

The German de-carbonization policy needs a reality check.

Chapter 1: Implications of the Paris Agreement for renewables and natural gas

Germany claims a pioneer role in promoting climate protection and in implementing the 2015 Paris Agreement. In fact, much of German energy and GHG policy was driven by efforts to comply with the Kyoto Protocol and inspired by the outcomes of the IPCC 4th assessment report. It is certainly interesting to look at the German example of promoting renewables as a major instrument to reach its decarbonisation goals, as an example of the potential contributions and drawbacks of a renewables-focused approach to meet the PA goals. For this, it is also important to look at the targets of the PA first and how they could be reached.

Main elements of the Paris Agreement[1] The main results of COP 21 in Paris as laid down in the 2015 Paris Agreement are efforts to stay within a global average temperature increase of 2 degrees Celsius (ideally, 1.5 degrees) above pre-industrial levels (Article 2). Article 4 sets out the aim for a GHG-neutral economy in the second half of the 21st century. In order to achieve this goal, every country has to submit its individual contribution (ratcheting it up over time), according to Articles 3 and 4.

The aim of staying below 2 or 1.5 degrees Celsius can be translated into staying within a given carbon budget (see below), limiting the accumulated amount of carbon that can be released into the atmosphere. This carbon budget is small compared to today's use, and may be eaten up easily ahead of time, highlighting the urgency of achieving a carbon-neutral energy world. Article 4 may be misread as saying that there is time until well into the second half of the 21st century to develop long-term sustainable solutions (i.e., renewable energy). This perception also risks overlooking shorter-term non-sustainable solutions, such as decarbonised natural gas or other hydrocarbons, capable of buying enough CO_2 emissions-free time for the development of an all-renewable electric world.

Details of the carbon budget The aim of staying below 2 degrees Celsius compared to pre-industrial levels[2] will be considered reached when staying within a GHG concertation of 450 ppm in the 21st century is achieved. About 70% of GHG emissions come from the use of fossil fuels, resulting in the amount of CO_2 that still can be emitted into the atmosphere in line with the 450 ppm target. The carbon budget left after 2015 is about 1,000 Gt of CO_2 or 750 Gt of CO_2, when assuming a likelihood of 50% or 66% respectively. Presently, the world economy produces 33 GT CO_2/year, which corresponds to a 30 years' reach, assuming constant emissions for the future.

The reach of the carbon budget in terms of final energy, depends on the average CO_2 content emitted per unit of energy consumed, i.e., on the share of renewables but also on the mix of fossil fuels. Per unit of energy, burning methane produces less CO_2 than liquid hydrocarbons, which, in turn, produce much less CO_2 than coal. There are further advantages to gas and clean liquids, such as LPG or clean gas oil: both can be used in gas turbines, while coal cannot. Gas turbines combined with steam turbines (CCGTs) achieve an electric efficiency of 55% to 60%, while steam turbines alone – the way coal-fired power works – only achieves a maximum of 45% electric efficiency. Switching to gas as much and as early as possible makes better use of the carbon budget.

Decarbonising natural gas (hydrocarbons) Keeping within the carbon budget implies that only a limited amount of proven fossil fuels (about 1/3) can be burned without decarbonisation.[3] It is predominantly coal that will be left in the ground, but oil and gas production also would come to a stop. While it is almost tautological that GHG free sustainable energy has to be renewable, the task given by the PA is achieving a GHG neutral world and staying within the carbon budget. Decarbonised hydrocarbon fuels can be used beyond the carbon budget in competition with renewables. (Details on decarbonising natural gas or hydrocarbons are given in Appendix 3) While fuel switching would buy time and make better use of the carbon budget, decarbonised natural gas would be part of the carbon

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[1] United Nations 2015: Paris Agreement, available under http://unfccc.int/paris_agreement/items/9444.php.

[2] With a 50 percentile likelihood.

[3] Chistophe McGlade & Paul Elkins, Nature 8 January 2015.

neutral world by using a major part of the energy contained in hydrocarbon reserves in a carbon-free way. It would also allow making further use of the existing resource base and related infrastructure, dampening potential geopolitical conflicts. Upstream decarbonisation would prevent the devaluation of gas reserves for gas-exporting countries. Also, it would reduce the risk of fully relying on a renewable electricity-only world, by maintaining an alternative (H_2) infrastructure for the transportation and storage of large energy volumes.

Can renewables be developed and deployed fast enough to keep within the carbon budget? Achieving a carbon-neutral world which is sustainable ultimately requires improving energy efficiency and meeting the remaining energy demand with sustainable carbon-neutral energy production, i.e., renewables. The question is, if progress on energy efficiency and development and deployment of renewables can be achieved in time for an all-renewable (predominantly electric) world to be installed when the carbon budget is used up. If not, at the latest when the carbon budget is used up, decarbonized hydrocarbons must be ready to fill the gap between energy demand and supply by renewables.

There are important differences between Germany and other countries, e.g. in geography, climate, industry and housing structure. However, the German examples of decarbonisation and development of renewables will give some indication if renewables can be developed fast enough on a global basis.

Chapter 2: German policy on decarbonisation and renewables

Germany has engaged in decarbonisation early on by fostering renewables and won praise for this from the international community. However, Germany's failure to meet its, albeit ambitious, decarbonisation targets for 2020 may be a sign that its decarbonisation policy, including the dominant role of renewables as an instrument to this end, is not achieving its objective and needs a thorough review. Chapter 2 shows the development of German policy regarding de-carbonisation and renewables, the development of major related legislation is given in Appendix 1.

Role of renewables in mitigating climate change The climate discussion at the Rio Earth Summit in December 1992 made it clear that decarbonisation of the energy sector would be a major challenge. At that time, renewables did not play a significant role in the energy sector, outside hydro dams and biomass. There was great scepticism whether other renewables could become competitive. It was therefore important to show that the costs of renewables could decline to a point where a sustainable energy world could be feasible without loss of welfare. As of 2000, the value of renewables was emphasised by the IEA's WEO.[4] However, costs were of concern: "the costs of renewable energy technologies have already fallen but further reductions are needed for renewables to compete with the least costly fossil-fuel alternatives."[5] Ten years on, in 2011, the IEA acknowledged that renewables were becoming cost-competitive on a broader scale.[6]

With the red-green government (formed by Social Democrats and the Green Party) elected in 1998, Germany was following a policy supporting the Kyoto Protocol and taking on a GHG reduction obligation of 21% for the first Kyoto Period (2008-2012). Fostering renewables was the main instrument to achieve it and was part of German industry policy as an export-oriented and technology-driven country.

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[4] IEA 2000: WEO 2000, p. 291: "More recently, policymakers have begun to recognise that renewables provide a broad range of benefits, including environmental and security benefits, but also contributions to portfolio risk reduction, utility system efficiency and customer preferences. … Many countries see them as part of national or international commitments to obtain emission reductions."

[5] IEA 2001: WEO 2001, p. 309.

[6]Reuters (nov.2011): Renewables becoming cost competitive.

Germany was a driving force at the international level, fostering renewables by the creation of the International Renewable Energy Agency (IRENA).[7] The German approach focused on fostering renewables was shared by many other countries, in line with the attitude of that time.

GHG reduction When it became clear that Germany would meet its target of a reduction of 21% of GHGs in the first Kyoto period, the German government embarked on the ambitious targets of the 4th IPCC assessment report. This report was acknowledged at COP 13 in Bali on 15 November 2007 which recommended limiting global climate change to 2 degrees Celsius.[8] On 7 December 2007, the German cabinet approved the first package for an integrated Energy and Climate Programme (*Paket zum integrierten Energie – und Klimaprogram der Bundesregierung*).

Nuclear phaseout and the new Energy Concept The role of nuclear has been creating strong controversy in German society for several decades. The main topic in the election programmes of both the Social Democrats and the Greens, who won the 1998 elections, was the phasing out of nuclear. An agreement negotiated with the nuclear operating utilities in 2000 about a phaseout with remaining tradable electricity volumes was put into law in 2002, so that nuclear would be phased out in the first half of the 2020s.

This was revised in 2010 by the new conservative liberal government (CDU/CSU/FDP), which prolonged the lifetime of nuclear reactors by approximately 12 years on average. The argument was that more time was won for the introduction of renewables by prolonging CO_2-free nuclear production and by feeding 50% of the extra income from prolonging nuclear into a special fund (*Energie- und Klima Fond*) to promote renewables. The new Energy Concept of 2010, triggered by the prolongation of nuclear, compiled systematically the main (old and new) components of the government's energy and decarbonisation strategy, to be implemented via subsequent legislation. While it was heralded as a major contribution to meeting the decarbonisation targets, the document itself rather emphasised its connection to the industry policy, fostering renewables as the main decarbonisation instrument[9] . No specific policy instrument addressed the decarbonisation of fossil fuels – which were, after all, the origin of most GHG emissions. The reduction of power plants' CO_2 emissions was left to the EU emissions trading system (ETS), which already at that time had created more problems than results.

After the Fukushima disaster in March 2011, the prolongation of the nuclear phaseout was revised back to the original scheme; otherwise the Energy Concept remained unchanged.

Measures triggered by the 2014 Progress Report: Action Programme 2020 The first Progress Report on decarbonisation efforts in 2014 revealed a substantial gap of 10 percentage points between the likely reduction of 30% and the reduction target of 40% by 2020, a gap of some 120 mln t/a GHG. As a result, the cabinet on 3 December 2014 issued the Action Programme 2020,[10] with 41 measures with a quantified range of CO_2 reduction intended to add up to an extra reduction of 62-78 mln t CO_2.[11] 22 mln t CO_2/a would be achieved by moving 2,700 MW of older lignite power plants into a climate protection reserve at a very favourable compensation (*Klimaschutzreserve*).[12]

2015 Germany and the Paris Agreement[13] Germany ratified the Paris Agreement on 22 September 2016.[14] On 14 November 2016, in line with Art. 4(19) of the Agreement, the German cabinet adopted

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[7] The founding act was signed in Bonn on 27 January 2009.
[8] The way ahead for the Bali Conference on Climate Change and beyond (COP 13 – COP/MOP 3)
[9]BMWi (sep. 2010): Energy Concept, p. 5: "These investments will, however, lead to lower energy imports and higher savings in terms of energy costs. Additionally, they will reinforce the leading position of German companies in the field of environmental and energy technologies."
[10] BMUB (December 2014)
[11] BMUB (December 2014), p. 26.
[12] FAZ (Oct. 2015): Lignite Exit Partially Decided.
[13] BMUB (2016): Climate Action Plan 2050 – Germany's long-term emission development strategy
[14] Bundestag (Feb.2018): Press release.

the Climate Action Plan 2050,[15] communicating long-term low greenhouse gas emissions development strategies.[16] "…With this plan, Germany will play its part in achieving the target set out in the Paris Agreement to keep global warming significantly below two degrees Celsius or even limit it to no more than 1.5 degrees Celsius."[17] It did not explain how Germany's actions will contribute to implementing Article 2 of the Paris Agreement, especially to keeping within the carbon budget implied by the 2 degrees Celsius target. [18]

Much of the National Action Plan 2050 replicated the 2010 Energy Concept. New was the split of the target for 2030 by sector (energy, buildings, transport, industry and agriculture), but it did not give details of how to reach those sectoral goals and did not fix it by a binding law.

The Plan is clearly focused on a vision of an all-renewable electricity supply, while rejecting (private or public) investment in the fossil fuel infrastructure or equipment, which would last beyond 2050: "the main concern here is to avoid stranded investments in fossil structures"[19] and to "…completely stop investing in fossil-fuel heating systems."[20] The Action Plan also shows the reliance on studies and scenarios in formulating the all-electric vision: "in that regard, an evaluation of numerous studies and scenarios shows that the German climate target is technically and economically achievable, in most cases based on known technologies."[21]

The deployment of another 250% of existing wind and PV capacity in Germany by 2050 (assuming a constant electricity consumption – not accounting for increases due to sector coupling) looks more than ambitious already with regard to locations and deployment speed, as well as the needed grid enlargement. At the same time, the storage problem for power from intermittent wind and PV is not anywhere close to a solution.

Coalition agreement of 14 March 2018 In the aftermath of the 2017 federal elections, the coalition agreement between the conservative CDU/CSU and the social democrats (SPD) became the first political document admitting that Germany would miss its 40% GHG reduction target by 2020, achieving only about 30%.[22] The new coalition agreement continues the previous approach to decarbonisation: more opportunities for German enterprises in international markets, using the country's pioneering role to support competitiveness and easing market access for German industry by promoting the Energy Concept worldwide.[23] To close the upcoming gap in GHG reduction, the only concrete measure is to aim at 65% renewables in power production by 2030, compared to the existing target range of 40-45% by 2025 and 55-60% by 2035. Otherwise, the agreement remains vague on how to reach Germany's climate goals.[24] It proposes creating a commission to produce an action plan **by the end of 2018**, showing how to close the gap for reaching the 40% reduction target **by 2020** and how to reach the 2030 target.[25]

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[15] https://www.bmub.bund.de/en/pressrelease/climate-action-plan-2050-cabinet-adopts-guide-to-climate-neutral-germany/.

[16] UNFCCC, Communication of Long Term Strategies, at: http://unfccc.int/focus/long-term_strategies/items/9971.php.

[17] BMUB (2016): Climate Action Plan 2050 – Germany's long-term emission development strategy. This is different from nationally determined contributions (NDCs). Those were submitted by the EU, based on an EU internal sharing mechanism.

[18] It is an interesting exercise to add up present GHG emissions and the amounts given by the decennial values, using linear interpolation up to 2050. Germany would emit about 1.5% of the global carbon budget of 1,000 GT of CO_2 (corresponding to the target of 2 degrees Celsius), while accounting for less than 1% of global population over that time.

[19]BMUB (Nov. 2016): Climate Action Plan 2050, p. 10.

[20] Ibid p. 11.

[21] Ibid p. 19.

[22] Coalition Agreement of March 14. 2018

[23] Ibid, *see* lines 3237-3239, lines 3243-3245, lines 3247-3250.

[24] "We are fully implementing the Climate Action Plan 2020 and the Climate Action Plan 2050 with the action packages and targets agreed for all sectors, and will make additions to close the action gap to reach the 2020 climate target as soon as possible. We definitely want to achieve the 2030 reduction target, " lines 6738-6742.

[25]Ibid., Lines 6748-6756.

Like all the previous documents, the agreement does not address the short and medium-term benefits of natural gas. Natural gas is only mentioned in the margin (in the context of sector coupling[26] and as a clean fuel for shipping in LNG form). There remains a plethora of measures, some very detailed; the present cacophony of energy taxation is not even mentioned.[27]

Commitment to GHG reduction, available instruments Germany ratified the Kyoto Protocol and the Paris Agreement, committing to their GHG reduction targets. However, Germany's commitment is imbedded in the commitments of the EU under the same Agreements and respective effort-sharing agreements inside the EU. The EU relies on different instruments at the EU level and the member state level to meet its obligations.[28] At the EU level it uses the ETS[29] for about 45% of present GHG emissions by handing out annually decreasing volumes of emissions trading rights. Individual Member States have no obligation to achieve specific reductions, this is left to the ETS market within the EU.

The reduction target for the remaining 55% in the non-ETS sectors (mainly transport, buildings, commerce and small industry, agriculture) is shared between Member States under the binding Effort Sharing Decision.[30] "…The Effort Sharing Decision sets binding annual GHG emission targets for Member States for the 2013-2020 period. The national emissions targets have been agreed unanimously by Member States."[31] Each State is free in its choice of instruments, subject to a monitoring and penalty mechanism. Having reached a reduction of 23% in GHG emissions in 2013, the EU has already surpassed its 2020 target of 20%.[32]

For the 2030 target under the Paris Agreement: "in October 2014, the European Council set the EU climate and energy targets for the period up to 2030, notably a 40% reduction in emissions of greenhouse gases, compared to 1990 levels. This target also serves as the EU's international commitment under the Paris Agreement. It is to be achieved by reducing GHG emissions in the ETS sector by 43% below 2005 levels, and emissions in the non-ETS sector by 30% below 2005 levels,"[33] corresponding to a reduction of 40% compared to 1990. (Emissions in 2005 were 7.9% lower than in 1990). The "… text is now expected to be put to vote during the March 2018 plenary session, after which it can be formally adopted."[34]

Germany's specific GHG reduction commitments are exclusively under the EU Effort Sharing Decision: 14% by 2020 compared to 2005, and 38% by 2030, compared to 2005.

Internally, Germany has its laws with binding targets on the nuclear phaseout, renewables and CHP. Issues of energy efficiency (e.g., in buildings) are dealt with by the cabinet through ordinances and action plans,[35] which transpose the corresponding EU regulation. The new Energy Concept was a policy statement adopted by parliament, not an act of binding legislation. Similarly, the Climate Action Programme 2020 and the Climate Action Plan 2050 are more policy statements by the government.

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[26] Ibid., Line 3342.

[27] When transformed into equivalent taxation related to the CO_2 content, the implicit tax rate for coal (other than in power) is 3.47 €/t CO_2; 7.87 €/t CO_2 for heavy fuel oil; while the tax on natural gas for heating is 30.23 €/t CO_2. *See* Felix Christian Matthes, "Decarbonising Germany's Power Sector: Ending Coal with a Carbon Floor Price?" p. 24.

[28] A 20% GHG reduction by 2020 compared to 1990 under the Kyoto follow-up, 30% by 2030 under the PA.

[29] The ETS covers six Kyoto greenhouse gases and power and heat production, plus emissions from the largest industry emitters: oil refineries, steel works and production of iron, aluminium, metals, cement, lime, glass, ceramics, pulp, paper, cardboard, acids and bulk organic chemicals.

[30] Effort Sharing Agreement. 406/2009/EC of 23 April 2009.

[31] European Parliament, Briefing EU Legislation in Progress, 5 February 2018, Effort Sharing Regulation, 2021-2030

[32] European Commission, UN climate conference makes progress on Paris Agreement implementation, Press release 18 Nov, 2017: http://europa.eu/rapid/press-release_IP-17-4740_de.htm.

[33] European Parliament Briefing EU Legislation in Progress, 5 February 2018, Effort Sharing Regulation, 2021-2030.

[34] Ibid.

[35] Such as the ENEV (*Energieeinsparverordnung*), the NAPE (*nationaler Aktionsplan Energieeffizienz*) or *Gebäuderichtline*.

Therefore, missing the targets set in these documents would lead to reputational damage but would have no legal consequences.

There is an annual monitoring process and a triannual progress report to review the implementation of the Energy Concept, but there are few instruments to steer the actual decarbonisation process. Promoting renewables, the preferred decarbonisation instrument, may have little effect in Germany but it reduces the demand for European emission allowances (EUAs) in the power sector, helping to keep their price low. In addition, with the low EUA prices, taking in more wind or PV will push the export of power from coal and lignite marginal production with low costs, which are only slightly increased by the EUA. This is a permanent barrier to changing the merit order between coal and gas-fired power. To overcome this situation, the EU would have to set more ambitious targets for the ETS, which is unlikely because of opposition from some Member States, but also in view of the effects on the chemical and steel industry, which might reinvest outside the EU. This suggests that Germany's ambitious decarbonisation target could be met only by imposing an extra carbon price or a carbon floor for power production at the national (or better, at coordinated regional) level, best to be paid in EUAs, to change the merit order in favour of gas over coal.

Chapter 3: Biogas and Power-to-gas

Biogas as biomethane and power-to-gas (PtG) in the form of methane or hydrogen are direct substitutes for natural gas, which are based on renewable energy. Both were regarded by the German Energy Strategy as obvious substitutes for fossil natural gas. While biomethane is already being produced, albeit very short of the original Energy Concept projections, power-to-gas is still in its pilot phase.

Biogas and biomethane In this paper the term "biogas" is used for all gas produced from biomass, and the term "biomethane" refers to the biogas, which is treated to the specification of the pipeline grid and consists predominantly of methane. [36]The share of biomethane in biogas in Germany is about 10%, and in absolute terms is close to 1 bcm/a (compared to Germany's annual gas consumption of about 85 bcm/a).

Biogas is an important pillar for the Energy Concept strategy. Compared to wind, it could contribute to meeting demand when electricity from wind and sun is low. The amount of biogas produced from agricultural waste and purpose-grown energy crops has increased dramatically over the past decade, but has almost stagnated in the last few years.

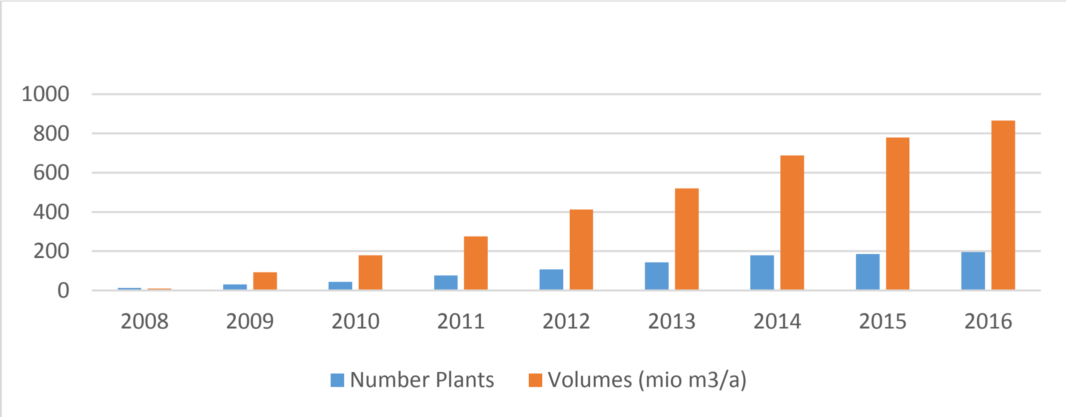
A major share of biogas is used for electricity production close to the source, since raw biogas from the fermentation process does not meet the specification of the natural gas grid, and the treatment of biogas to methane is costly. In 2016, a total of 31.75 TWh of electric power was produced from about 7 GW of mostly small CHPs based on biogas, which is a 1.5% increase compared to 2015.[37] From 2017 to 2019, a maximum capacity of 150 MW will be added annually.[38]

[36] For an overview on technologies, costs etc. on an international level, see Martin Lambert, Biogas: A significant contribution to de-carbonising gas markets? OIES 2017

[37] BMWi (Sept. 2017): Renewable energy in numbers p.8.

[38] Bundestag (July 2016) Renewable Energy act amendment 2017

Figure 1: Biomethane: Number of Plants, Annual Volumes



Source: BDEW, based on DENA, BNetzA

The original goal of the Energy Concept of reaching 6 bcm/a of biomethane feed-in by 2020 was dropped.[39] The treatment of biogas to methane proved to be too expensive, even more so in an environment of low gas prices.

Overall limitations of biomass and biogas production Biomass is produced from bio-waste stemming from normal agricultural processes and from harvesting purpose-cultivated energy crops. Independent of costs and prices, any further development of biogas is restricted by the limited availability of agricultural land, competition with the production of other biofuels, and competition of biomass and food production, generally. The relatively optimistic estimates for the REN (renewables) potential by BMWi, the German Ministry of Economy and Energy, show that Germany already used 60% of the long-term potential of biomass production in 2015.[40] The massive underachievement of the transportation sector in reducing GHG emissions and the dropping share of biofuels in transportation since 2011 will likely create pressure to increase biofuel production for this sector and limit the prospect for a further increase of biogas production.[41]

The production of biomass can only be expanded further at the cost of a substantial environmental impact. Biogas from waste disposal has grown slowly over the past years and will not increase substantially. Any further increase in biogas production will have to come from energy crops and will therefore be in competition with food production. Figure 2 shows a strong increase in land use for biomass production in Germany from 2005 to 2012, from 1,400,000 ha to 2,400,000 ha (or a CAGR of 8%). Since 2012, this steep hike seems to have reached a plateau, probably correlating with higher food prices and the hunger crisis in many least developed countries in 2011.

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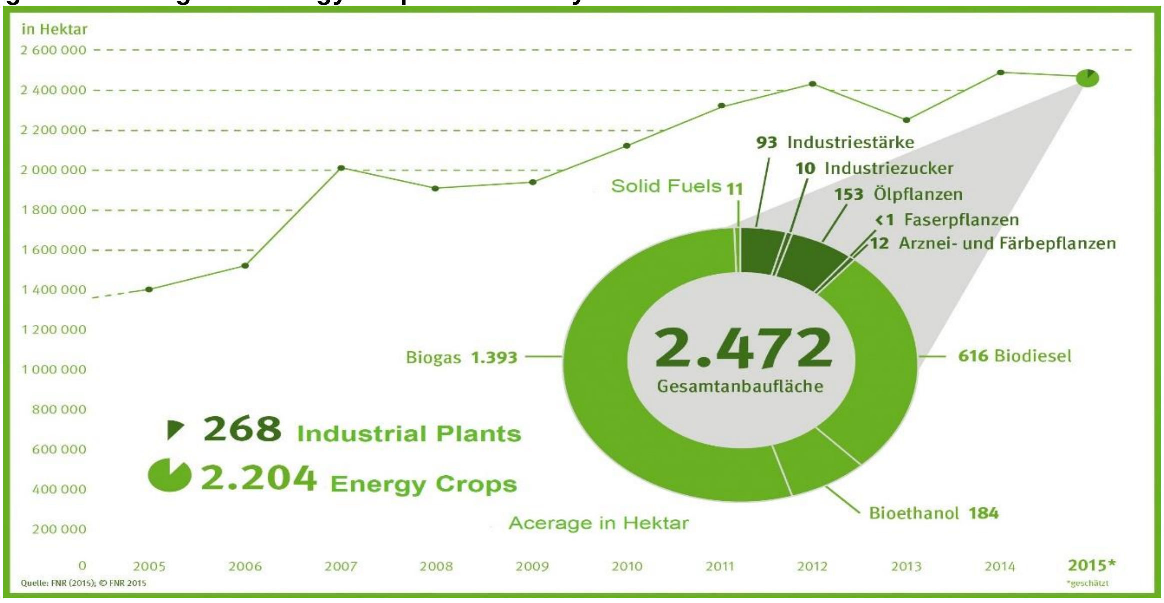
[39] DENA (July 2010): Biomethane in CHP and Heatmarket.
[40] BMWi (Dec. 2016): 5. Energy Transition Report.
[41] BMWi (Sept. 2017): Renewable energy in figures.

Figure 2: Acreage for Energy Crops in Germany 2005-2015



Source: FNR (2017)

Power-to-gas Power-to-gas (PtG) may be the most promising technology for integrating the different energy-related sectors of transport, heat production and power generation, which is known as sector coupling. PtG appears to be the all-in-one solution addressing the crucial problems of the Energy Concept. Surplus power from wind and photovoltaic can be transformed by electrolysis into hydrogen and then methane, which can be fed into the gas grid and into existing gas storage, to be used when wind and solar power is low.[42] Applied on a large scale, PtG would offer not only the solution to storage problems of a mostly REN-based power system, but also the answer to an insufficient power grid by using the existing gas infrastructure to transport surplus REN power.

Currently, there are 30 pilot projects for PtG in Germany, and the available electrolysis capacity grew fast over the last years, reaching 20 MW in 2017.[43] In 2018, a 5 MW power-to-gas electrolysis unit will go online in Hamburg, and a 10 MW unit will be finished by 2020 near Cologne. However, today PtG is still too costly to be applied on a large scale. Even though some progress was made in the last couple of years concerning efficiency and price/performance ratio, more research will be needed.

Hydrogen from electrolysis is the simpler process, but hydrogen is also more difficult to integrate into the gas grid (maximum 5-10% under the present gas specification for the grid), while PtG methane can replace natural gas without restriction.

The question remains open whether to improve the methane production process based on hydrogen from surplus renewable electricity, or to transform the natural gas grid/system into a grid/system to carry (decarbonised) hydrogen from renewable sources, which could also handle decarbonised methane from geological sources.

From today’s technological perspective, when aiming at an 80-95% GHG reduction, PtG may be the answer, particularly for the transportation sector (air traffic, ships, trucks), but also for some industrial applications, as well as for seasonal energy storage.[44] PtG technology with its potential progress has apparent system benefits and is compatible with the already developed biomethane sector. Because of

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[42] BMWi (April 2018): Power to Gas.
[43] DENA (June 2017): Presentation Roadmap Power to Gas.
[44] DENA (June 2017): Presentation Roadmap Power to Gas.

this, the use of natural gas as a transitional fuel in transport, heat and power generation appears to have more appeal. Not having the lock-in effects of electricity, it would mean low investment costs and provide the high flexibility urgently needed for a stable electricity system. However this would need substantial cost reductions and scaling up, needing not years but decades.

Chapter 4: Heating Sector (non-industrial)

This Chapter looks at the heating sector as the most important sector of natural gas sales, in which natural gas has the highest share. There are various policy instruments of the New Energy Concept which have an impact on the overall heating sector (energy efficiency/saving and the role of district heating) or specifically on the position of natural gas in the heating sector challenged by renewables

Structure and main drivers of the heating sector The heating sector consists predominantly of space and water heating for residential, commercial, industrial and public buildings, but also includes industrial heat needed for production processes. The Energy Concept goal for the heating sector as a whole is to reduce CO_2 emissions by 20% by 2020 and by at least 80% by 2050, compared to 2008. The latest data suggests that the 2020 emissions reduction target might not be reached, while the announced 14% REN share for 2020 looks feasible, as 13.2% was achieved in 2015.

In 2016, Germany's overall energy use for heat[45] was 4,945 PJ (*see* Table 1), which corresponded to 54% of total final energy consumption of 9,152 PJ. [46] Currently, major government policies aim at reducing energy consumption in the heating sector by promoting renewables and energy efficiency. So far, the focus has been on imposing higher efficiency for residential buildings; efficiency standards for commercial building follow with some delay. Industrial buildings play a negligible role in energy consumption, so they are excluded from efficiency restrictions for heating.

Table 1: Heat Consumption in Final Energy Sectors

Petajoule	2014				2015				2016			
	Space heating	Water heating	Process heat	Total heat	Space heating	Water heating	Process heat	Total heat	Space heating	Water heating	Process heat	Total heat
Industry	163.6	16.1	1662.4	1842.1	166.3	16.3	1678.9	1861.4	159.4	16.4	1713.1	1888.9
Transport	12.4	0.0	0.0	12.4	12.4	0.0	0.0	12.4	12.7	0.0	0.0	12.7
Business, commerce, services	634.2	62.8	92.4	789.4	675.7	65.2	97.4	838.3	720.8	68.0	102.8	891.6
Households	1472.6	332.3	138.5	1943.5	1584.3	332.7	137.6	2054.7	1664.3	345.3	142.2	2151.8
Total	2282.8	411.3	1893.4	4587.5	2438.7	414.1	1914.0	4766.8	2557.2	429.7	1958.1	4945.0

Source: Arbeitsgemeinschaft Energiebilanzen, Anwendungsbilanzen fuer die Endenergiesektorn in Deutschland in den Jahren 2013 bis 2016, Stand 11/2017

The residential and commercial sectors account for a large share of gas in Germany's total gas consumption (31.4% and 14.7% respectively in 2016). Most of that gas is used for space and water heating or by CHPs for district heating. Industry accounted for 38.2% of heating, mostly for process heat. This is discussed under Chapter 5. It is important for natural gas to take a competitive position in the heating sector *vis-à-vis* energy saving and renewables both in residential and commercial and in industry. This will be decisive for defining the future role of gas in Germany.

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[45] Space and water heating accounts for 60% of energy consumption in the heating sector, the remaining 40% is process heat predominantly in industry.
[46] BMWi (Jan.2018): Energy data complete edition.

Heating systems (in residential and commercial) in Germany There is a variety of heating systems in Germany, which date back to different phases of the energy market. In general, there was a free choice of heating systems, so that several different heating systems and the corresponding infrastructure can be found in the same street, e.g., gas heating, oil heating and electric night storage, together with some remaining coal ovens. In some newly developed residential areas there could be an obligation to use gas or district heating or, in some areas, night storage. There was a slightly different development in East Germany, which still had a high share of lignite heating in 1990, which was often replaced by gas after unification. Many cities in the eastern part of Germany have a high penetration of district heating. The broad variety of heating systems makes it difficult to define a coherent approach to reforming the sector, given various interests related to different modes of heating.

Development of the building stock, social drivers The rate of new construction permits has been increasing from less than 200,000 in 2010 to about 350,000 in 2016. This compares to a building stock of about 41.7 mln dwellings in 2016.The existing building stock and related infrastructure (traffic, electricity and gas grids) settlement structures cannot be changed easily. New (carbon-neutral) buildings tend to compensate for population growth and the increasing living space per person. When old buildings are torn down, they are replaced by state-of-the-art new ones. However, replacing all old buildings is not an option, so the main challenge is refurbishing existing buildings in order to achieve a mostly carbon-neutral building stock.

Until recently, Germany was a country without strong population dynamics, which resulted in a relatively stable building stock. By 2050, the share of new buildings will be about 16% in the residential sector and 35% in the commercial sector by BMWi estimates.[47] This means that current policies have to focus on existing structures with low energy efficiency in order to lower GHG emissions substantially in the building sector.

Table 2: Apartments and Living Space

	Unit	2000	2005	2010	2014	2014 on 2000, percent
Dwellings	Thousand	38 383	39 551	40 479	41 221	7.9
Total living space	Million square meters	3 245	3 416	3 681	3 769	13.9
Average living space per dwelling	Square meters	84.6	85.8	90.9	91.4	7.4

Source: Statistisches Bundesamt 2015, Bautaetigkeit, Wohnungsbestand in Deutschland, https://www.destatis.de/DE/Publikationen/Thematisch/Bauen/Wohnsituation/FortschreibungWohnungsbestandXLS_5312301.html (eingesehen 14.04.2016)

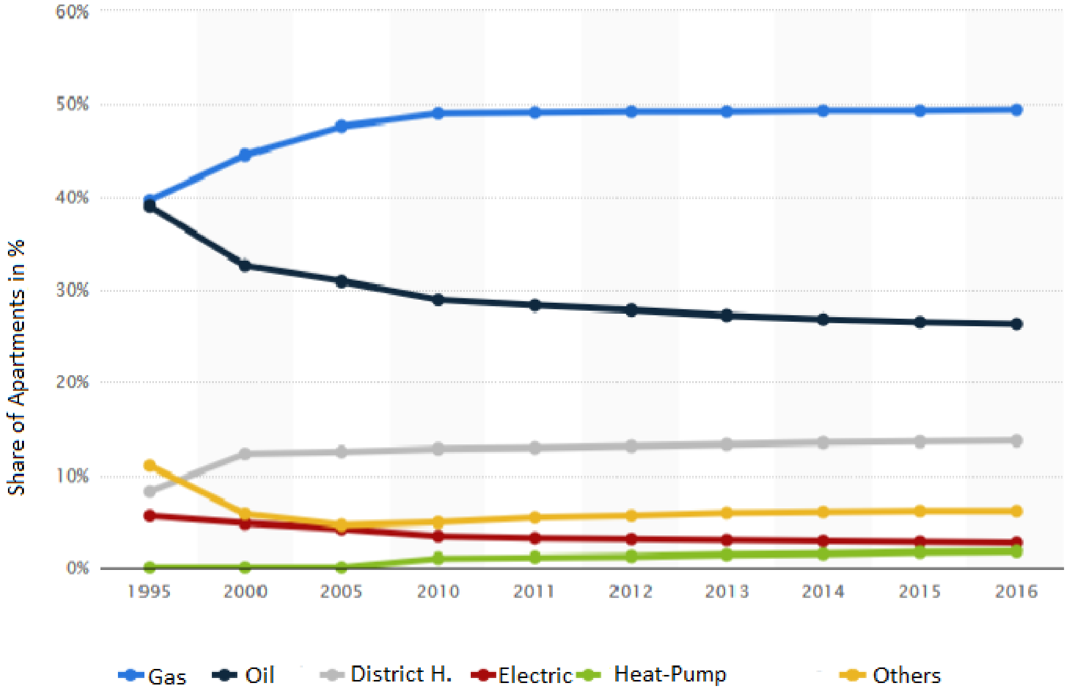
In this regard, a particular challenge is the continuing trend to larger apartments (*see* Table 2) and growing living space per person, which reached 46.5 m² in 2014 up from 39.5 m² in 2008[48]. This development is related to a rise in wealth, but also to changing demographics.

At present construction rates, few older buildings will be replaced with new ones. With the rate of refurbishing the energy efficiency of existing housing hardly reaching 1%, higher energy efficiency will just compensate for the growth of average living space per person. It has long been recognised that energy efficiency improvements would be crucial to the overall success of the Energy Concept.

Fuels used in heating In 2016, 49% of existing households were heated by gas directly, and 13% relied on district heating with gas as the dominant generation fuel. The share of oil in heating has declined from 40% to 27% since 1995.

[47] Agora Energiewende (Feb. 2017) : Changing Heatsupply 2030.
[48] Own calculation based on table 2 and official population statistics.

Figure 3: Share of Heating Energies



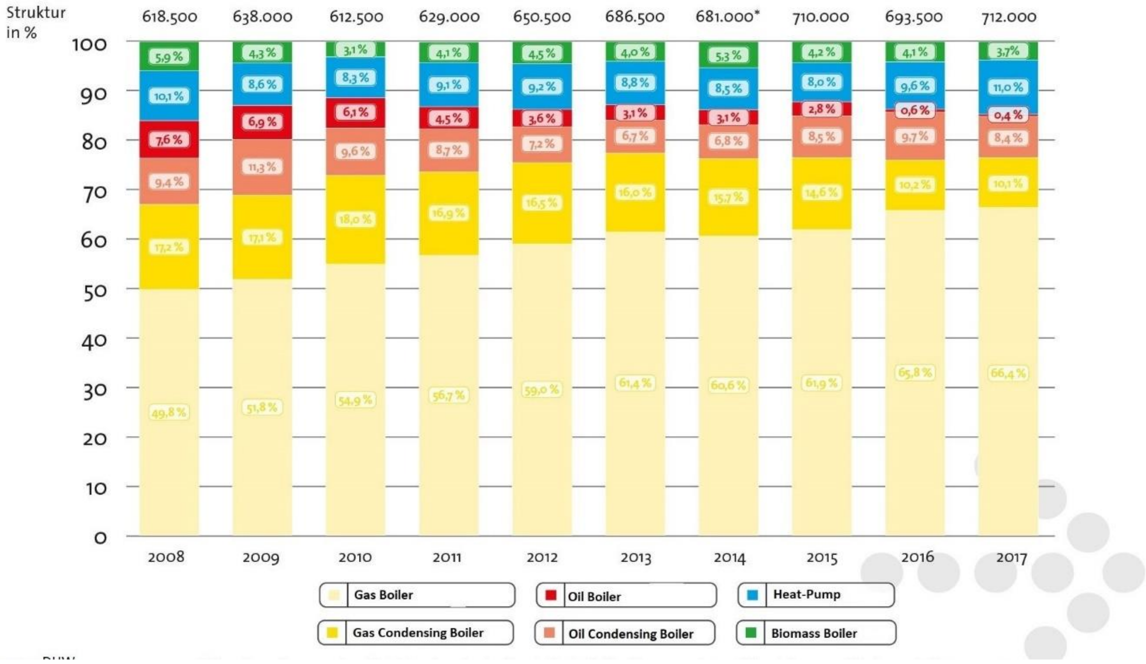
Source: Statista (2017)

For new dwellings, the share of gas heating has shrunk from 77% in 2000 to 50% in 2015, while the share of district heating has grown from 7% to 21%. The strongest development between 2004 and 2014 was the increased installation of heat pumps (from less than 1% to 21%), and wood/pellets heating (from 1.2% to 6.2%).[49]

Sales of gas-fired central heating devices, including replacement, have increased from about 66% in 2005 to 75% in 2014, while the share of oil-fired boilers has shrunk from 25% to less than 10% over the same period. The share of heat pumps and biomass boilers together lay between 10% and 15% from 2006 to 2014 with varying splits.[50]

[49] BMWi (dec. 2016): 5. Energy Transition Report.
[50] Ibid

Figure 4: Sales of Central Heating Devices



Source: BDH (2018)

Due to unclear regulations, there is a backlog in the replacement of heating systems. About 40% of all fossil-fuel heating boilers in Germany are 25 years old or older. Since it is mandatory to renew boilers 30 years old or older, many of the existing systems will have to be replaced in the coming years. So far, no competitive renewable alternative exists for most of these systems, so they will be replaced with new gas where grid connection is possible or oil burners.

Many old boilers are run on oil, so there is GHG saving potential in switching from oil to gas, but there is also potential in replacing old gas boilers with new gas condensing boilers, which are in general 15% more efficient than conventional gas boilers.[51] The German Energy Agency DENA reports that while the sales of insulation materials were down by 11% in 2015 compared to 2012, the market for efficient oil and gas boilers grew by 10% over the same period.[52].

In 2015, the KfW (the Government owned bank used for internal and external development projects) handed out €52 mln in credits and subsidies for the installation of 14,100 oil boilers. Sales were up by 30% compared to 2014 (while the deployment of REN heating systems was slowing down).[53] Unlike in other European countries, the price for heating oil in Germany including taxes is low. Higher taxation would offer an incentive for fuel switching.

Pending massive policy changes against using gas it looks as if the losses of gas to renewables so far might be compensated by further replacement of oil heating so that overall gas sales in the heating sector could be stabilized.

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[51] BMWi (Nov..2015): Energy efficiency Strategy for buildings p.23.
[52] DENA (Dec. 2017): press release.
[53] Klimaretter.info (March 2016): Press release: Germany Supports Oil-boilers.

4.1 Energy Efficiency

Government policy The main tool for fostering energy efficiency in Germany is the Energy Saving Regulation (*Energieeinsparverordnung*, or ENEV). ENEV's most important aspects for energy efficiency in the heating sector are the rules for new and existing buildings. In accordance with the ENEV, annual primary energy use/m^2, in buildings constructed after 2016 should not exceed 45 kWh/m^2 [54] (compared to an overall average of 136 kWh/m^2 in 2015).[55] To achieve this, ENEV sets out requirements for insulation, efficiency of heating methods and a minimum share of renewables in the energy mix for space and water heating (usually 50% of heating energy). In order to reach the ENEV standard, renewables can be replaced by district heating (mostly in the case of inner-city buildings) or by higher energy efficiency.

For existing buildings, minimum requirements have to be fulfilled. Heating systems in general have to be replaced if they are 30 years old or older and, in cases of a general refurbishment, ENEV sets minimum efficiency standards for insulation and heating systems. Certain insulation measures are mandatory, particularly the insulation of basement ceilings and attic floors; rooftops have to be insulated if the attics are used as a living space.

A major indicator of the progress of energy transformation in the heating sector is the rate of refurbishment of the existing building stock. To reach the targets of the Energy Concept, an annual refurbishment rate of close to 2% is needed. For 2012, a rate of 1% was reported, which stagnated, if not fell, during the following years. The official expert review of the Energy Concept report suggests that both the short and long-term success in meeting the set goals will depend strongly on achieving a higher refurbishment rate for energy efficiency in existing housing.[56]

The German government's concept of ecological transformation of the housing sector is laid out in the Strategy for Energy Efficiency in Buildings, *Energieeffizienzstrategie Gebäude* (ESG).[57] The ESG anticipates a maximum energy saving potential of 40-60% for heating and cooling by 2050, compared to the 2008 energy demand.[58] Although called a strategy, the ESG is rather a theoretical model of how goals for the building sector could be achieved. Basically, it considers the technical potential for efficiency and REN in the heating sector and deduces what minimum contribution from efficiency and REN has to be reached to meet the Energy Concept goals. Considering the short time span left until fundamental actions have to be taken, there are few tangible ideas or advice in the ESG on how the technical potential could be realised. The strategy states that actions are needed for higher rates of insulation of the building stock; at the same time, it downplays the urgency by assuming an unrealistic high refurbishment rate of 1.2-1.3% for the trend scenario.[59] Taking into account the latest sales of insulation materials, the current energy efficiency refurbishment rate is closer to 0.9% and falling.

Development so far So far, the government's policy of subsidising insulation and renewables, as well as introducing higher energy saving standards for new buildings has shown some success. The temperature-adjusted energy demand for heating in residential buildings had declined from 151 to 130 kWh/m^2 (an impressive 14%) over the period from 2008 to 2012, although it climbed back up to 136 kWh/m^2 in the following years, corresponding to a reduction in demand of 11.1% between 2008

[54] Wikipedia (April 2018): Energy efficiency house standard 70.
[55] BMWi (Dec. 2016): 5. Energy Transition Report, p. 40.
[56] Expert committee for the Energy Transition (Dec. 2016): Expert review of the Energy Transition report 2016.
[57] Agora Energiewende (Feb. 2017): Changing Heat Supply 2030, p. 8: "According to this solution space (ESG), the final heat energy consumption of households, commercial and industrial buildings can be reduced by an average of 40 to 60% (in comparison to 2008). Even more building efficiency seems difficult given a variety of restrictions".
[58] BMWi (Nov.2015): Energy efficiency Strategy for buildings.
[59] Prognos (Dec. 2015): Energy efficiency strategy for Buildings, background information, p. 43.

and 2015.[60],[61] This development shows an inverse correlation with the development of energy prices, so it may be explained by a combination of government policy and high prices, leading to investment in higher heating efficiency. Consumers' sensitivity to energy prices influences their daily behaviour, which may explain the change in heating efficiency figures after 2012.[62]

The main insulation materials currently used are rock wool (54%) and polystyrol (32%). Rock wool is suited for insulating new buildings and inside existing buildings in attics and for ceilings in cellars. It is more expensive and more difficult to handle than polystyrol, but is fire-resistant and also has good noise insulation properties. The energy efficiency refurbishment of external walls of the existing building stock is done predominantly with polystyrol. Here, its market share is 80%, since it is much lighter and can be fixed easily to the surface of buildings.

Spending on the refurbishment of the energy efficiency of residential buildings went down from €40.1 bln in 2010 to €34.8 bln in 2014 (a CAGR of -3.5%). In volumetric terms, sales of insulating materials for refurbishment decreased from 21.9 mln m^3 in 2012 to 19.7 mln m^3 in 2015 (a CAGR of -3.3%). This trend is likely to continue and even reinforced after the Grenfell Tower disaster.[63]

Figure 5: Sales of Insulation Materials in 1000 m^3

Source DACH (2017)

The continuous negative media coverage of house insulation since 2012 may have contributed to the low investment, as well as the fact that only a particular segment of the building stock is suitable for a cost-efficient refurbishment. Typical post-war multi-story apartment buildings were mostly build in large housing estates, which lowers the specific cost of renovation. The same applies to their rather functional plain facades. Many of these housing estates already have been refurbished, meaning that the remaining building stock offers a smaller savings potential, often insufficient for an economically feasible

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[60] BMWi (Dec. 2016): 5. Energy Transition Report, p. 40.

[61] However, this improvement, corresponding to a CAGR of 1.4%, is almost cancelled out by an increase in living area per person from 41.2 m^2/person in 2005 to 46.5 m^2/person in 2014, or a CAGR of 1.3%.

[62]BMWi (Nov.2015): Secondreport on renewable heat act, paragraph 58.

[63] The Grenfell Tower fire broke out on 14 June 2017 at the 24-storey Grenfell Tower block in London. It caused 71 deaths and over 70 injuries. The very rapid spread of the fire is thought to have been accelerated by the building's exterior cladding fixed to the outside of the walls by thermal insulation of similar composition to Polystyrol.

insulation of the facades. The savings potential of insulation inside houses is declining as well. Such simple measures as the insulation of basement ceilings and attic floors are mandatory and have largely been implemented.

Several disadvantages linked to the insulation of facades came to public attention after the first insulation boom in the 1990s. Often the refurbished buildings did not reach the expected savings due to installation problems. Reports of massive mould on the facades of insulated buildings, shorter than expected durability of materials, materials containing poisonous and genome-changing fire retardants, insulation materials acting as a fire accelerant, as well as the daylight-reducing embrasure effect, contributed to the low popularity of insulation measures, especially for houses built before WW II, where monument protection and aesthetic reasons often prevent insulation measures.

The 2017 fire catastrophe at the Grenfell Tower in the UK led to a debate about fire safety in Germany, with firefighting experts demanding higher standards for the commonly used polystyrol insulation material.[64] A representative of the insulation material industry gives a pessimistic outlook on the industry's prospects in the aftermath of the Grenfell Tower tragedy.[65]

4.2 Renewable energy in the heating sector

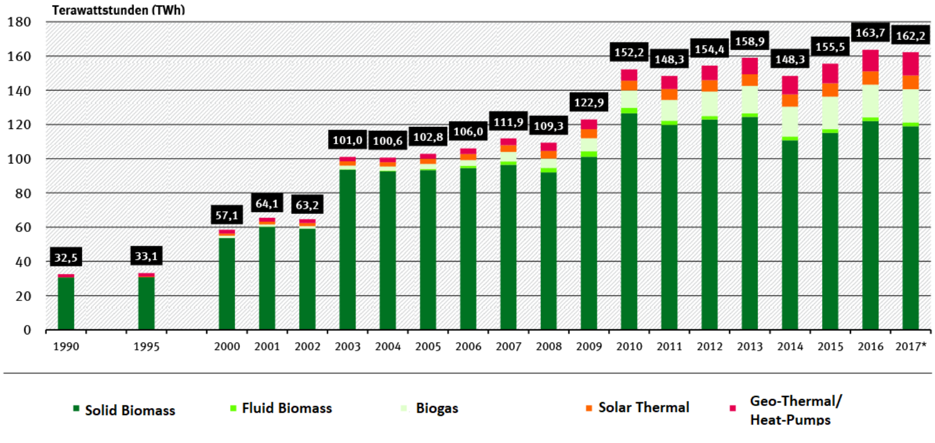
Role and development of renewables in primary energy consumption Renewables appear to be the only form of energy, which are sustainable and GHG-free. The contribution of renewable energy to Germany's primary energy consumption progressed from 200 PJ in 1990 to more than 1,600 PJ in 2016, an impressive increase of more than 700% over 20 years.

Due to the limits of biomass production (competition with food production and counterproductive effects on CO_2 absorption), there is not much potential to increase the use of wood, biogas or biodiesel. Hydropower is restricted naturally due to Germany's landscape and precipitation. PV is comparatively expensive and runs into storage issues. The main expansion potential appears to lie with wind power combined with heat pumps.

The role of renewables in the heating sector Most renewable energy is used in the heating sector (biodiesel is used in transport, and power generation uses PV, wind, hydro and biogas). From 2010 to 2017, energy from renewables in the heating sector increased slightly from about 152 TWh to about 162 TWh. The overwhelming share (75%) of renewables used in the heating sector (industry, commercial and households) is solid biomass. It is followed by biogas and gas from landfills (12%), environmental heat, or heat pumps (6.6%), and solar thermal energy (4.9%).

[64] FAZ (June 2017/1): Why a fire like the Grenfell catastrophe is unlikely in Germany.
[65] FAZ (June 2017/2): The end of insulation?

Figure 6: Heat Consumption from Renewables



Source: Umweltbundesamt (2018)

About half of all produced renewable heat (80 TWh) is used in residential buildings (*see* Table 3). Here, the split of renewable energy use for heating is very specific: electric heat pumps are used in buildings exclusively with one household, solar thermal is used in buildings with up to two households. Buildings with more than two households only use, but to a small extent, solid biomass. Solid biomass used directly accounts for about 80% of renewable energy for household heating; this is mainly the case of houses with one or two apartments, which indicates that the use of firewood is confined to either rural areas or fireplaces in higher-income households.

Table 3: Heat Consumption from Renewables in Households by Building Types

		Solid biofuels	Solar thermal	Heat pumps (environmental heat)	Total
EEV heating, renewable	TWh	66.8	6.3	7.5	**80.6**
Including in one-family houses	TWh	38.6	3.5	7.5	**49.6**
Including space heating	TWh	35.5	0.6	7.1	**43.2**
Including water heating	TWh	3.1	2.9	0.4	**6.4**
Including in two-family houses	TWh	21.3	2.8	-	**24.1**
Including space heating	TWh	19.7	0.4	-	**20.1**
Including water heating	TWh	1.6	2.3	-	**4.0**
Including in apartment buildings	TWh	7.0	-	-	**7.0**
Including space heating	TWh	7.0	-	-	**7.0**
Including water heating	TWh	-	-	-	**-**

Source: Prognos, Fraunhofer ISI, DLR, Oko-Institut, KIT

Potential of biomass Currently, 88% of renewables in the heating sector come from biomass, which will continue to deliver the largest share in renewables growth until 2020.[66] The production of biomass, mainly wood and biogas, cannot be expanded further without a substantial environmental impact. Increasing the already high rate of wood removal from German forests would not be sustainable and would jeopardise the forests' ability to absorb and store sufficient amounts of CO_2.

In 2015, about 300 PJ of heat were produced from biomass. The German Ministry for Energy and Economy (BMWi) expects that in 2050 no more than 500 PJ of heat will be produced from biomass,

[66] BMWi (dec. 2016): 5. Energy Transition Report: p.17.

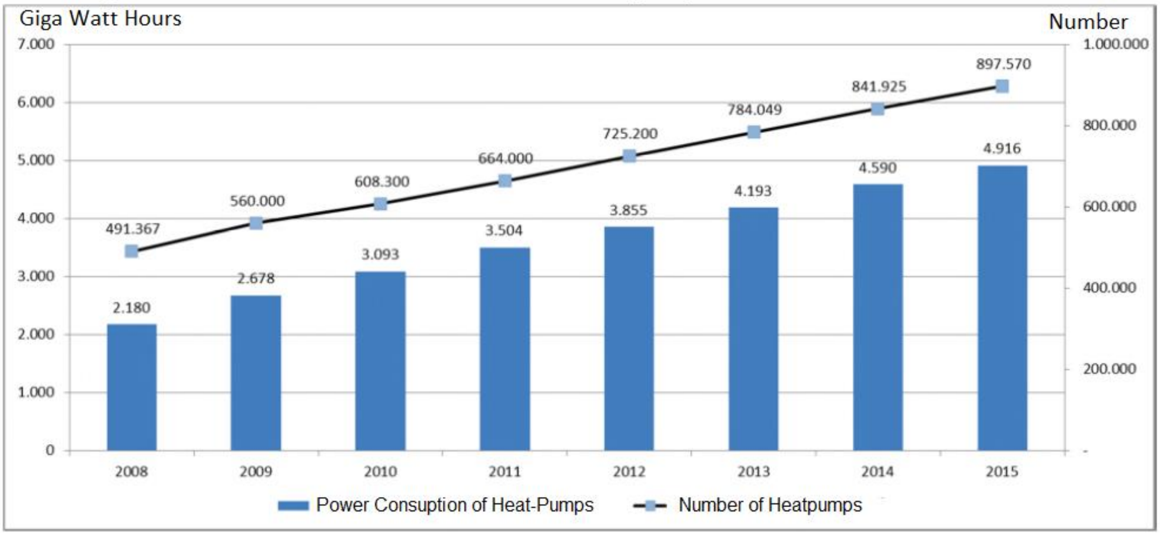
including higher imports. A moderate total increase of 10% by 2030 would lead to a total thermal energy output from biomass of 330 PJ.

Potential of heat pumps Earth-source pumps and air-to-water pumps are used for decentralised heating. Despite the many restrictions and higher investment costs for earth-source pumps, they are the more efficient solution, since sub-terrain temperatures are higher than ambient air temperatures during the heating season. High costs and negative side effects, such as the sinking/rising of ground levels or even small earthquakes, made the earth-source heat pump less popular during the last decade. In 2008, the ratio of the two types was close to 50/50. In 2014, only ¼ of installed heat pumps were earth-source heat pumps.[67]

Air-to-water pumps are easier to deploy and have lower investment costs, but their efficiency (heat output relative to electric power consumption) can be as low as 200% at lowest air temperatures compared to 300% to 400% at higher temperatures pushing the power demand of air-to-water heat pumps during cold periods to extreme peaks.[68]

Both heat pump solutions have disadvantages and barriers to deployment on a massive scale.[69].

Figure 7: Number of Heat-Pumps and Power Consumption of Heat-Pumps



Source: Bundesumweltamt

Currently, there are approximately 1 mln heat pumps installed in German households, with a relatively stable deployment of 55,000 new heat pumps annually. About 2/3 of these heat pumps are installed in new houses and only 1/3 in existing houses.[70] This is the result of ENEV's mandatory requirement of 50% REN for newly built homes, on one side, and high restrictions on the installation of heat pumps, particularly in densely built areas, on the other hand.

The 2017 Prognos paper 2017 *Changing Heatsupply 2030*, commissioned by the German Ministry for the Environment (BMUB), is an attempt to construe a viable way to solve the Energy Concept-related challenges for the heating sector. In the presented scenarios, the anticipated gap in REN heating sources is closed by an enormous increase in the number of heat pumps. It is assumed that to meet the 80% goal by 2050, the number of installed heat pumps will have to reach a minimum of 6 mln by

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[67] BMWi (Nov. 2015/1): Energy Efficiency Strategy for buildings, p.18.
[68] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030,, p. 40 and following.
[69] BMWi (Nov. 2015/1): Energy Efficiency Strategy for buildings, p.16.
[70] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030, p.40 and following.

2030. The trend scenario operates with a moderate annual increase of 90,000 heat pumps. However, in order to reach 6 mln by 2030, an average of 360,000 new heat pumps will have to be installed every year.[71] Even reaching an annual rate of 90,000 new heat pumps would require some regulatory incentives. A 360,000 average will only be possible with massive subsidies and easing of restrictions, as well as banning fossil-fuel boilers (and running into spatial restrictions in densely built areas).

It is unclear how these barriers can be overcome in the available timeframe. A sharp cost decline cannot be anticipated, although air-to-water heat pumps still have some potential for improving efficiency.[72] Furthermore, a much higher electric power demand in the winter will pose an additional challenge for Germany's power grid and REN power production to reach the Energy Concept goals for the electricity sector. For a scenario with only 3.9 mln heat pumps, the Prognos report estimates an additional 17 GW peak demand only for heat pumps, roughly ¼ of total power peak demand in Germany today.[73]

Potential of solar thermal energy Solar thermal's contribution to heat production in Germany was 20 PJ in 2016.[74] At the current growth rate, there will be about 30 PJ of solar thermal energy available by 2030.The potential of solar thermal energy by 2050 is estimated at between 40 PJ and 290 PJ, depending on the study and the method of calculation.[75] The central disadvantage of solar thermal is its counter-cyclical heat production. Particularly in Germany, where sunshine in the winter is not sufficient to guarantee economical heat production based solely on solar thermal energy. The other major disadvantage is limited sun-exposed space close to heat demand, where solar thermal is in competition with more efficient and easier to integrate photovoltaic systems, which are experiencing continuing cost declines, unlike solar thermal energy systems. This explains the decrease in the installation of solar thermal energy systems from about 2 mln m^2 in 2008 to 0.74 mln m^2 in 2016.[76]

4.3 District Heating

Production District heating (DH) is the established and so far the only centralised heat production system. Heat for district heating grids can be produced by special heating plants (HP), or as a by-product of combined heat and power (CHP), or by using waste heat from industrial processes. Heat production in heating plants has some economic and, less so, GHG advantages compared to individual heating due to economies of scale, which are partly eaten up by the need for a heat distribution grid with extra investment and heat losses. The advantage of CHP is that it uses the low-temperature exhaust heat from power production, which would be wasted otherwise, and comes at almost zero extra energy use. In that respect, by making better use of the energy input, CHP can be regarded as an efficiency measure.

Consumption District heating in Germany is spread very unevenly and is confined mostly to cities, particularly in the eastern part of the country. It is installed more frequently in newly built homes where its share is growing, from 7% in 2003 up to 23.4% in 2016.[77] This trend goes back to the 2001-2002 edition of the ENEV, where DH was the only heating system based on fossil fuels allowed in new houses without complementing it with a minimum share of 50% REN or higher than usual insulation. In 2016, the share of district heating in final energy consumption in heating in buildings was 10%, or 75 TWh, with 13% of all households being heated by DH.[78]

[71] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030, p. 42.
[72] BMWi (nov. 2015/1): Energy Efficiency Strategy for buildings, p. 25.
[73] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030, p. 13.
[74] BSW (Feb. 2018) Federal association for the solar economy: Statistics Solar thermal energy.
[75] Agora Energiewende (Feb. 2017): Changing Heat Supply 2030, p. 41.
[76] BSW (Feb. 2018) Federal association for the solar economy: Statistics Solar thermal energy.
[77] BDEW (Nov. 2017): Statistic on installed heatingsystems
[78] BMWi (Dec. 2016): 5. Energy Transition Report.

Particularly within big cities, district heating is often the only way to comply with ENEV regulations, which explains its success even if it is more expensive than fossil fuel heating systems.[79]

Competitive situation of district heating In the period from 2000 to 2014, the costs for district heating were 35% higher than for heating with oil and 16% higher than for natural gas.[80] This disadvantage of DH is aggravated by lower fuel costs in recent years, as well as by a drop in prices for electric power, the main by-product of CHP plants. Prices for district heating vary greatly from city to city, which usually own DH companies. These local monopolies have been subject to anti-cartel measures numerous times in the past; cross-subsidisation of DH companies' power branches or feeding the city budget by surplus from the heating sector can be observed frequently.[81]

Potential Studies show that potentially 32% of all households in Germany could be reached by district heating.[82] The *Wärmewende* 2030 Report by Prognos estimates that to achieve a 95% GHG reduction in the heating sector by 2050, a minimum DH share of 20.5% in final energy consumption will be needed to complement decentralised REN heating sources, hardly available in urban core areas.[83]

The general trend towards higher efficiency through insulation, as well as the shortening of the heating season are particularly problematic for the economic viability of DH. As the average consumption per connection falls, so do the earnings per connection. To make district heating more attractive, it needs a higher density of grid connections and further penetration into the existing building stock, so that it becomes more reasonably priced.

Fuel input In 2016, most DH was run with CHP plants (83%), complemented by heat plants (15%) and some industrial waste heat (2%). Heating plants are mostly smaller units in proximity to low-density settlements; they may be upgraded to CHP plants, though current economic conditions and electricity prices prevent investment. The share of heating plants has stagnated in the past.

In terms of energy input into CHP plants for general electricity production in 2016, the fuel mix was: 42.4% natural gas, 22.8% coal, 15.3% REN, 9% lignite and 10.2 others.[84] (see Figures 8 and 9) The overall share of renewables in CHP is still relatively low in Germany, though experts consider its potential in district heating to be high. To compare, in Denmark, where the DH share in heating is above 60%, renewables are at 50%.[85]

Net power production from CHPs continuously grow from 2003 to 2010, then stagnated until 2015. The initial increase was mainly due to the construction of plants based on biomass and of gas-fired CHPs. By contrast, power production from CHPs based on hard coal and fuel oil decreased over the same period. 2016 saw a growth in heat production (see Figures 8 and 9), and consequently of power production, due to lower temperatures, which was almost exclusively based on extra gas supply, probably due to lower natural gas prices.[86]

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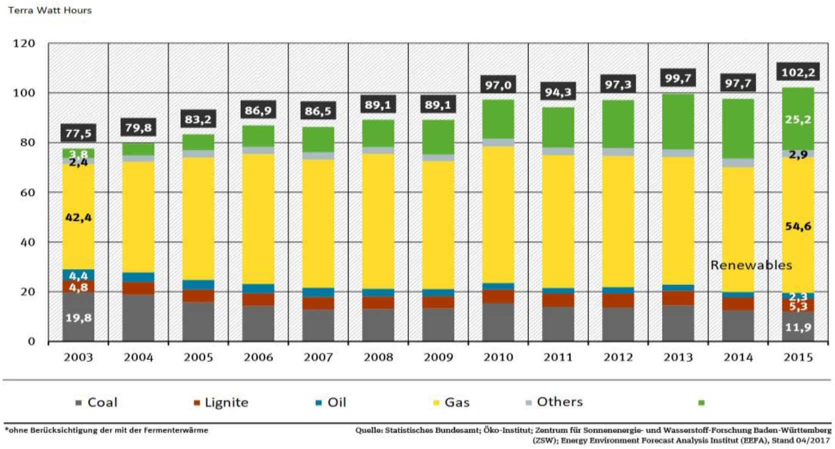
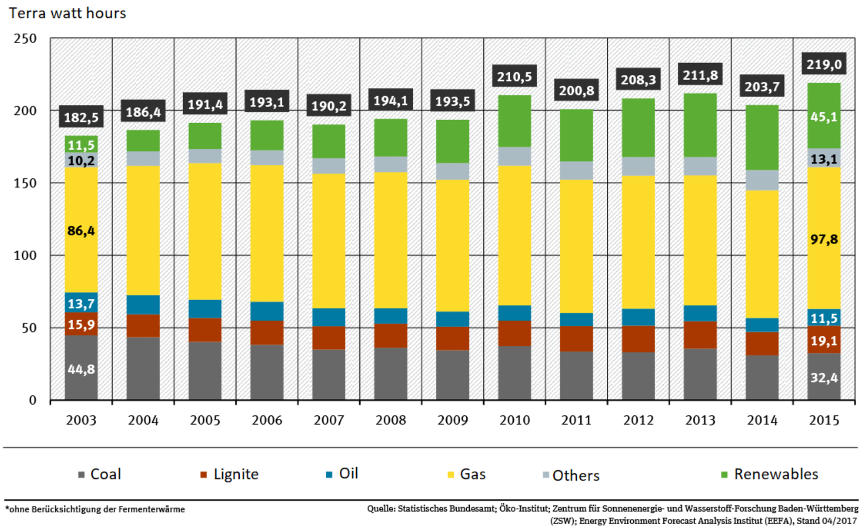
[79] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030.
[80] BDH (Aug. 2016): Central vs. De-central heatsupply, p. 33.
[81] BDH (Aug. 2016): Central vs. De-central heatsupply, p. 41.
[82] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030, p. 28.
[83] Agora Energiewende (Feb. 2017): Changing Heatsupply 2030.
[84] AGEB (Sep. 2017): Inquirry on energy statistics 2017
[85] BDH (Aug. 2016): Central vs. De-central heatsupply, p.30, p.39.
[86] Umwelt Bundesamt (March 2018): Chart on fuel statistics for CHP plants.

Figures 8 and 9: Electricity and Heat Produced in CHP Plants in Germany in Twh





Source: Umwelt Bundesamt (March 2018)

Comparing figures 8 and 9 reveals that the share of gas in power production is higher than the share of gas in heat production. That can be explained by the higher electric output of gas-fired CCGTs compared e.g. to coal-fired plants. In a CCGT, about 55% of energy input is transformed into electricity, and up to 45% of waste heat can be used for heating purposes. By contrast, even modern coal-fired power plants have a maximum electric efficiency of 45%, so that up to 55% and more of the energy input results in waste energy.

In the short term, the replacement of coal-fired CHP plants with those run on natural gas promises to be a fast and relatively easy way to achieve GHG reductions. Presently, a gas-fired CHP plant in Germany emits 148 g CO_2/kWh, while coal-run CHP plants emit 622 g CO_2/kWh.[87] Since 2016, gas-fired CHP plants are paid 0.6 Euro cents per kWh of electricity produced as an incentive to move away from coal. This incentive does not appear to be very effective; in 2016, only 300 MW of coal-fired

[87] CO²EmissionenVergleichen(march 2012): Comparison of CO² emissions

capacity was replaced by gas-run CHP plants and qualified for fuel-switching subsidies.[88] Low electricity prices and the ever-growing EEG levy prompted the German government to revise its target of 25% CHP-based power in gross power production. The current target is 110 TWh by 2020 and 120 TWh by 2025.[89] With 85.8 TWh of electric output in 2016, these goals still appear optimistic, considering the current financial incentives for the CHP sector. Many new gas-run CHP plants will have to be built over the coming years to be able to replace coal in the not too distant future.

4.4 Conclusion on gas and renewables in the heating sector

This chapter focussed on the use of gas and renewables in the private (non-industrial) heating sector, mainly in buildings. Sales of gas suffered from various de-carbonization policies, namely promoting energy efficiency/saving, use of renewables and district heating. However, in the next decade and beyond this can partially be compensated by replacing old oil-fired boilers and by an increase in the share of gas-fired CHPs stabilizing gas sales.

So far the contribution of these policies falls short of the decarbonisation policy targets. While newly constructed houses (have to) comply with ambitious standards, this just compensates for the effects of population growth and a tendency to smaller household size and larger living space per person. For the existing building stock the energy efficiency refurbishment rate (about 1%) continues to fall short of the 2% needed for achieving the decarbonisation goals. Insulation of existing houses is stagnant if not declining and heat pumps, considered to be the renewable energy with a large potential, is developing steadily but slowly and faces many obstacles especially in city areas. Due to the scattered heating structure in Germany district heating is facing a low consumption density in many areas resulting in high specific costs.

Target scenarios meeting the future policy targets need to make assumptions, e.g. on an increase in the installation of heat pumps far beyond past development and certainly not feasible without major policy changes and a resulting devaluation of existing infrastructure and appliances.

However, the continued use of natural gas would not contribute to the decarbonisation goals either, as long as it is not of carbon free origin like bio methane or renewable power to gas or alternatively hydrogen from decarbonised natural gas.

Chapter 5: Industrial Processes

With 226 TWh, industry was the largest power consumer in 2016, ahead of the commercial sector with 149 TWh and households with 129 TWh. Industry also had the highest share of gas sales in 2016 – 38%, or 355 TWh, ahead of the residential sector with 31%, or 290 TWh, and the commercial sector with 16%, or 136 TWh.[90]

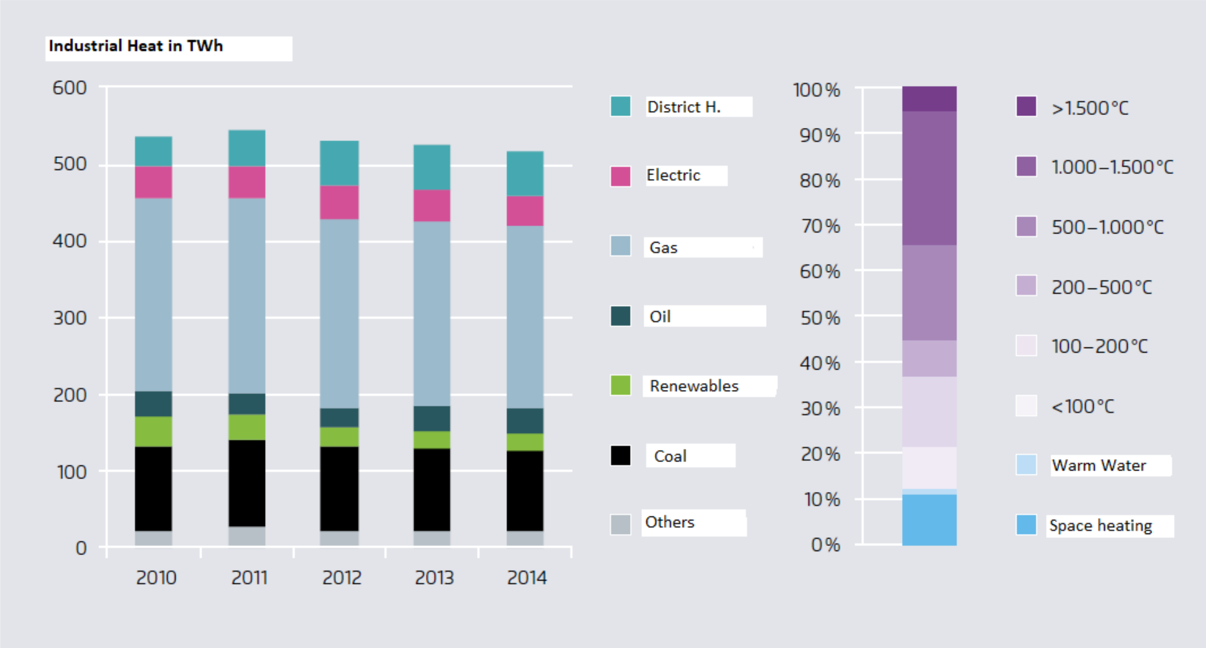
In 2016, there was still a high share of coal in industry – 17%. There should be a substantial potential for gas to replace coal; such a change would lead to significant GHG reductions. By contrast, renewables were only at 4.8%, corresponding to 31 TWh of final energy consumption. Use of renewables in industry is confined to waste in the paper and pulp industry and there is little perspective that it will increase. [91]

Heat consumption by industry Heat consumption in industry in 2016 was 1,889 PJ overall of which process heat with 1,713 PJ was the dominant share with room heating at 159 PJ and warm water having minor shares. Industry requires heat of different temperatures (see figure 10). Power generation can

[88] BMWi (Oct. 2017): Answer of the federal government to a question asked by MP of the green party by Rainer Baake.
[89] BMWi (March 2018): Combined Heat and Power
[90] BDEW (March 2017): Gas figures 2017 for the German gas market.
[91] AEE (June 2017): Renewables for the Industry p.3.

produce only exhaust heat of less than 500 degrees Celsius as a by-product.[92] More than 50% of industry's heat requirement is at temperatures of 500 degrees Celsius and higher, which CHP cannot provide. At the same time, the CHP potential for heat in industrial processes could rise to an estimated 66% in the near future, according to the BMWi. Heat for production processes, which need temperatures above 500 degrees Celsius, will continue to be supplied directly from fossil fuels or electricity.[93]

Figure 10: Industrial Heat Consumption in TWh



Source: Agora Energiewende (Feb. 2017): Changing Heatsupply 2030

The potential for more CHP in industry While all the power generated by power plants run by industry uses the waste heat of the power process, not all heat production is linked to a power generation process. Waste heat is normally rather a by-product of power production, looking for a heat sink; in industry, the heat sink is already there and a power generation process can be added upfront, adding to the overall efficiency. The ratio between heat production and power production is clearly higher in industrial CHP plants than in CHP plants feeding into the public grid. Mostly gas-run CHP plants currently deliver approximately 20% of the heat required by industry, suggesting a substantial potential for adding power production to heat production.

Power consumption, industrial CHP sector The industrial sector accounted for 43.8% of German electricity consumption in 2016. Of the 226 TWh of electricity consumed, 34.6 TWh were produced in CHP plants for exclusive industrial purpose, which at the same time produced 90.4 TWh of heat for the industry,[94] [95] the remainder being taken from the public grid.

The price of electricity for industrial customers in Germany consuming between 500 MWh and 2000 MWh annually is already the highest in the EU.[96] This means that there is little margin for higher energy taxation in the sector to foster energy efficiency, since it is particularly exposed to international

[92] The exhaust stream from gas turbines is up to 500 degrees Celsius, from steam turbines – usually below 200 degrees Celsius.
[93] Agora Energiewende (Feb.2017): Changing Heatsupply 2030 p.31 and following.
[94] Umwelt Bundesamt (April2018): Website of BMU, graphic sectoral share power consuption
[95] AGEB (Sep. 2017): Evaluation table for the German energy balance p.16.
[96] BMWi (Jan. 2018): Energy data complete edition table 41

competition. Energy-intensive manufacturing could leave Germany, if electricity prices rose significantly compared to other EU countries.

The CHP study by Prognos and Frauenhofer Institut estimates in its base scenario that between 2012 and 2030 CHP power production for the industrial sector could rise by 52.6%, while its political scenario shows an increase of 87.1%. Comprehensive planning and financial incentives through the KWKG are advised to develop further the CHP potential for the industrial sector.[97]

GHG emissions GHG emissions from industry do not include the emissions from power supply from the grid. Power production by own industry power plants, which are *de facto* all CHP plants, is attributed to industry.

In 2014, heat production of 1,842 PJ for the industrial sector was responsible for 21% of all energy-related GHG emissions in Germany. Space and water heating only accounted for about 10% of heat demand in the industrial sector, which was dominated by process heat with a share of 90%.

The energy policy for the industrial sector should aim at raising the CHP share of heat and electricity production to enhance energy efficiency and cut GHG emissions. This results in higher gas demand, since new CHP plants for the industry must be run exclusively on gas.[98]

In some cases, waste heat from industrial processes can be used for district heating, although in practice, the long- and short-term inflexibility of household heat demand is often difficult to harmonise with the conditions of industrial production.

Industry also emits non-CO_2 GHG gases, namely perfluorocarbon (CF_4 and C_2F_6) in the aluminium industry and nitrous oxides in the production of nitric, adipic, glyoxal and glyoxylic acid. Emissions of these GHG gases together with CO_2 emissions are covered by the ETS system, which now applies to 28 industrial activities, including power and heat production.[99] Given that the largest part of industry is covered by the EU ETS, not many instruments are left to Germany to promote GHG reduction in the industry sector. The main instrument is fostering CHP, which, if effective, will overlap with the EU ETS.

Hydrogen consumption in industry With regard to the introduction of decarbonised hydrogen, a major issue is how to create and develop demand on which to base (in fact, to pay for) the necessary modification of production and infrastructure.

The largest consumers of (so far non-decarbonised) hydrogen are in industry: mainly refineries, chemical plants and steel production. There is little public information on production and consumption of hydrogen in industry. According to a recent press article the overall amount of hydrogen consumed annually in Germany is about 20 billion m^3, about 70% of which is produced by a reforming process (emitting CO_2 into the atmosphere) and 30% by electrolysis.[100] Probably (according to information from the industry) the share of hydrogen produced by electrolysis is much lower and the overall volume of hydrogen consumed is much higher.

Replacing hydrogen produced by industry, which emits the resulting CO_2 into the atmosphere, by hydrogen produced through a reforming process with capture in the gas-producing field or another geological structure, might be a readily available starting point for the marketing of decarbonised methane as carbon-free hydrogen.

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[97] BMWi (Oct. 2014): Potential and cost-benefit analysis of the potential applications of combined heat and power p.114 and following

[98] Ibid: p.116.

[99] The first phase of the ETS only covered CO_2 and 10 industrial activities (Directive 2003/87/EC). Directive 2009/29/EC extended coverage to nitrous oxide and perfluorocarbons and altogether 28 activities. *See* Annex 1 of EU Directive 2009/29/EC of 23 April 2009.

[100] FAZ (Feb.2018): Press article

Conclusion Renewables in industry play a minor role with little upside potential and are confined mainly to waste products from the paper and pulp industry. Gas plays the major role in energy supply to the industry because it is easy to handle and can produce process heat above 500 degree Celsius, which is half of the demand in industry. Gas has the highest share in fuelling CHPs but there is still a substantial potential to replace coal in existing CHPs and to use more gas by adding more CHP production (replacing power from the grid) and thereby reducing GHG emissions. The policy dilemma is that large industry is subject to the EU ETS, which does not work so far and is not likely to work until the structural oversupply is overcome. For the future, hydrogen consumption in industry might work as a starting point for demand of carbon-free hydrogen.

Chapter 6: Power Generation

This chapter deals with competition between gas-fired power and electric renewables in the short and long term, the role of gas in decarbonisation and in reliability of power supply, the phasing out nuclear power, the adequacy of capacity and the role of the power grid.

6.1 Policy issues

When looking at Germany's Energy Concept, the most important question is whether the instruments defined to implement its policy are effective, i.e., able to deliver the policy goal, in this case, Germany's fair global contribution to meeting the 2 degree Celsius goal of the Paris Agreement. With regard to the most important target of the Energy Concept, namely the 40% reduction of CO_2 emissions by 2020 compared to 1990, Germany will clearly miss it, even if one subtracts the CO_2 emissions due to net electricity export, now almost 10% of German power production. "Without these significant net electricity exports, Germany would be 4-5 percentage points closer to meeting its emissions reduction targets for 2020."[101] [102] [103] [104]

Germany is likely to reach the following 2020 targets:

- 14% of renewables in heat production; this is a relatively safe target, and there is no target set for beyond 2020,
- phasing out nuclear according to plan (another plant to be closed at the end of 2019, the last six are after 2020) without a negative impact on the reliability of power supply, and
- 35% of renewables in power production.

Germany's policy instruments on decarbonisation in the heating sector have had limited success with little chance of improving anytime soon (as shown in the previous chapters), and progress in the transportation sector is not coming. Therefore, the focus is more and more on renewable electricity as the dominant instrument to deliver the goals of the Energy Concept.

6.2 Developments during 2010-2017

In the 2011 discussions about the closure of nuclear plants, much attention was given to the issues of whether Germany would become import dependent, mainly on French nuclear imports or Polish coal power, and whether Germany's power supply would become less reliable. There is no indication so far of either of those scenarios being realised: Germany's net power exports have been ever increasing

[101] Matthes F. C. (Dec. 2017): "Decarbonising Germany's Power Sector: Ending Coal with a Carbon Floor Price?", Notes de l'IFRI,.

[102] The rough calculation is 50 mln t CO_2 emissions per 50 TWh power production based on hard coal, if all export is attributed to hard coal or lignite. This compares to an emissions gap of 150 mln t between today's ca 900 mln t CO_2 (GHG) and the target of 750 mln t CO_2 (GHG), which corresponds to 60% of GHG emissions in 1990.

[103] Agora Energiewende (Feb. 2017): Press release 5.2.2017

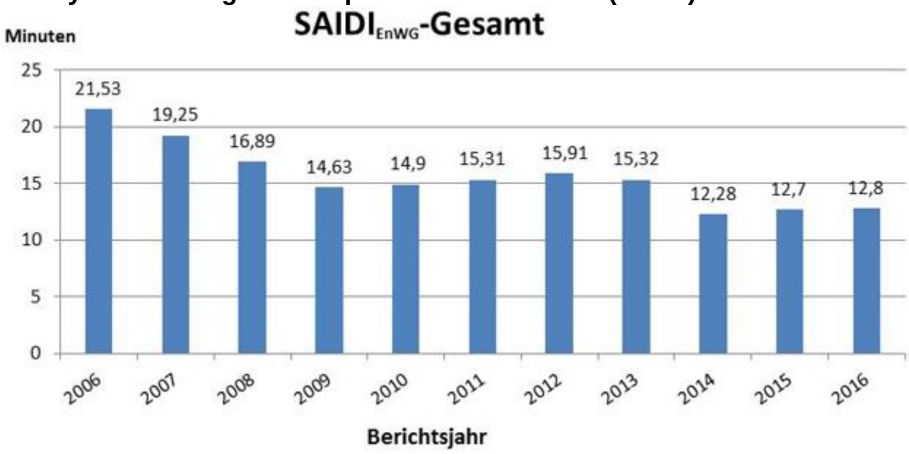
[104] Umwelt Bundesamt (Feb. 2018): GHG emissons in Germany.

since 2011, and in 2017 have reached 54 TWh, or almost 10% of generation. Peak exported capacity reached 14 GW in March and 15 GW in December 2017.

Keeping with the schedule fixed by law, eight nuclear reactors were shut down in 2011, one was closed in 2015[105] and another one in 2017;[106] the last seven[107] will be closed by 2022.[108] These reactors have a total gross electric capacity of just under 10 GW, three with 4,310 MW are in Northern Germany, four with 5,687 MW are in Southern Germany. Shutting down the reactors in Northern Germany will not create grid problems, as wind energy is growing in the north and reliable fossil power is available from nearby North Rhine Westphalia. Closing nuclear in the south is more problematic in view of the constraints on the grid connection between the north and the south.

While it is unclear how these upcoming challenges will be resolved, so far at least the closing of nuclear has had no negative impact on the reliability of power, as measured by the system average interruption duration index (SAIDI).[109] The SAIDI in Germany, one of the lowest in the EU, even improved slightly since 2011.

Figure 11: The system average interruption duration index (SAIDI)



Source: Bundesnetzagentur (23 Nov. 2017) Quelle: BNetzA 2017

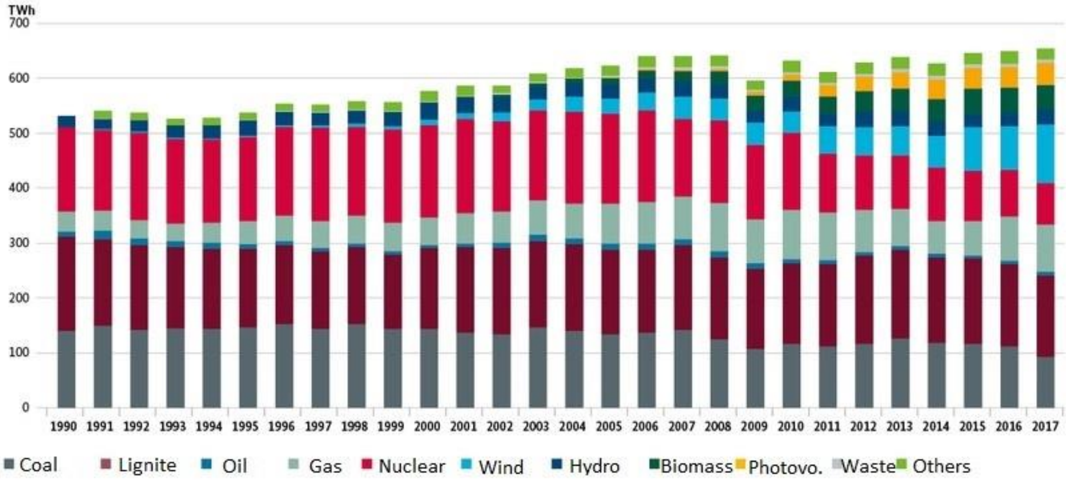
Development of capacity and generation in 2010-2017 While during the period from 2010 to 2017 nuclear capacity shrank according to schedule, fossil fuel-based capacity was almost stable with 79.4 GW in 2010 and 80.2 GW in 2017. Lignite remained stable at 21.3 GW, but hard coal went down from 28.4 GW to 25.0 GW, oil-fired capacity reduced from 5.9. GW to 4.4 GW, compensated by an increase in gas-fired power from 23.8 GW to 29.5 GW.[110] However, without nuclear capacity, the remaining total thermal capacity of 80 GW will fall short of the peak demand of 85 GW expected by the IEA for 2022.[111] While there is about 9 GW of pump storage linked to the German grid (in Germany, Luxembourg and

[105] Grafenrheinfeld (Bavaria).
[106] Gundremmingen B (Bavaria).
[107] Phillipsburg 2 (Baden Württemberg) at the end of 2019; Grohnde (Lower Saxony), Gundremmingen C (Bavaria), and Brokdorf (Schleswig-Holstein) at the end of 2021; and the last three – Isar 2 (Bavaria), Emsland (Lower Saxony) and Neckar Westheim (Baden Württemberg) – by the end of 2022.
[108] Umwelt Bundesamt (Jan. 2018): Nuclear powerplants in Germany.
[109] Bundesnetzagentur (April 2018): SAIDI index of power Interuption probability.
[110]Frauenhofer Institut (Feb. 2018): Chart on installed capacity.
[111] IEA (2013): Energy Policies of IEA Countries, Germany 2013 review, p. 149.

Austria), this covers only a few hours (with a total volume of around 56 GWh),[112] and a certain reserve margin would be needed.[113]

By contrast, renewable capacity almost doubled from 63.8 GW to 112.2 GW over the period. Non-intermittent renewable capacity was stable (hydro from 5.4 GW to 5.6 GW) or increased moderately (generation based on biomass from 6.2 GW to 7.4 GW). The main growth came from intermittent power: wind capacity more than doubled (onshore wind from 26.8 GW to 50.9 GW, plus 5.3 GW offshore in 2017) and PV increased by 75% (from 25.4 GW to 43.0 GW).

Figure 12: Gross Electricity Generation in Germany by Energy Sources



Source: BMWi (Jan.2018): Energy data complete edition Fig. 27

Since 2010, gross domestic consumption went down slightly from 614.7 TWh to 600.2 TWh in 2017, while net exports increased from 17.7 TWh in 2010 (6.3 TWh in 2011, when eight nuclear plants were taken off the grid) to 54.0 TWh in 2017.

Nuclear production went down from 140.6 TWh in 2010 (108.0 TWh in 2011) to 75.0 TWh in 2017, in line with the closing down of nuclear plants. Lignite was stable, developing from 145.9 TWh in 2010 to 148.0 TWh in 2017. Hard coal increased from 117 TWh in 2010 to 127.3 TWh in 2013 and then fell to 94.2 TWh in 2017, while natural gas decreased from 89.3 TWh in 2010 to 62.0 TWh in 2015, but then increased substantially to 81.3 TWh and 86.0 TWh in 2016 and 2017 respectively.

Production from renewables increased from 123 TWh in 2011 to 210 TWh in 2017,[114] corresponding to 35.0% of gross domestic electricity consumption. This increase of 97 TWh, was partly compensated by a reduction of 32 TWh in CO_2-free nuclear production, while the total of gas and hard coal production went down by 18 TWh (lignite being stable). The remaining 46 TWh from the increase of renewables production correspond to the increase of net exports by 48 TWh from 2011 to 2017.

The increase in renewables compensated for the loss of production from one nuclear plant shut down in mid-2015 and led to a reduction in the total gas and coal-fired production (corresponding to about 20 mln t CO_2 emissions per year). However, it did not go beyond that, particularly, it did not push out any lignite-based power production. Instead, net exports increased by 46 TWh (approximately 50 mln t

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[112] This compares with the energy contained in German gas storage of 24bcm working gas as of 1 January 2017, or about 260 TWh, which is 5,000 times the volume of pump storage.

[113] IEA (2013): p. 149.

[114] As with all the following figures, quoted/calculated based on gross annual electricity generation in Germany since 1990, AGEB

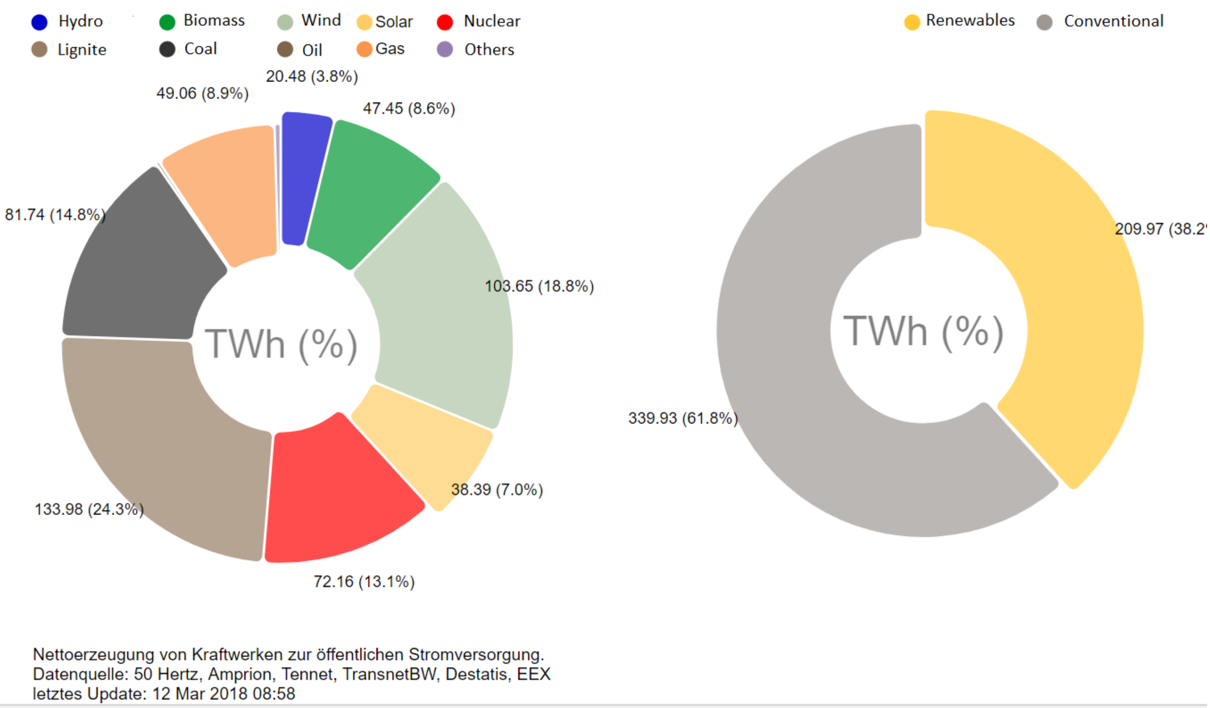
CO_2/year emissions), pushing out power generation in other EU countries with most likely lower specific CO_2 production than German lignite. This may make economic sense, given the low marginal costs of German lignite, but does not improve the CO_2 balance of Germany nor of the EU as a whole, even if it might improve on paper the balance of individual importing countries. Germany's net income from power exports in 2017 was €2 bln.[115]

Increasing the share of renewables in Germany, the main decarbonisation instrument, did not translate into decarbonisation on a corresponding scale because of growing power exports. This illustrates the danger of not addressing decarbonisation goals with policy instruments specific to decarbonisation, as well as the problems of the policy overlap between the renewables policy of the German government and the defunct ETS.

6.3 Evaluation of 2017

In 2017, net power generation stood at 546 TWh, domestic consumption at 493 TWh, and the net export/import balance at 51 TWh.

Figure 13: Net Electricity Generation in Germany 2017



Source: Frauenhofer (2018) Retrieved from: https://www.energy-charts.de/

In 2017, lignite was still the largest source of net power production with 134 TWh (or 24.2%), ahead of wind power with 103.6 TWh (18.8%), hard coal with 83 TWh, nuclear with 72 TWh, and gas-based power with 47 TWh. Overall, 38.3% of domestic net power production was based on renewables. Only 23.5% of power production was based on imported energy (hard coal and gas). The year 2017 set a new record in net electricity production from renewables in Germany: 210 TWh were produced from run-of-river hydro, PV, biomass and wind:

[115] Frauenhofer Institut (Jan. 2018): Press release.

- Run-of-river hydro (without pump storage) with a capacity of 5.6 GW in 2017 had a relatively constant production of 21 TWh, depending on precipitation.
- PV, which has had by far the largest share of subsidies via the EEG, has an installed capacity of 43 GW at end 2017. Still, the 38.4 TWh of PV electricity produced in 2017 falls short of the electricity produced from biomass, which is subsidised much less via the EEG.
- As demonstrated in Chapter 3, biomass (mainly biogas not processed to biomethane) is used in a large number of small power plants with or without heat production with continuous feed-in. In 2017, capacity was at 7.4 GW and production at 47.6 TWh. Biomass has some remaining potential for load following, which is not yet used.
- The largest volume of renewable power, 103.4 TWh in total, came from wind energy (installed capacity onshore: 50.9 GW, offshore: 5.3 GW) with an average load of 1,850 h/a. For onshore plants, the load factor was about 2,000 h/a for plants close to the coastline, and 1,200 h/a for inland Germany.[116] Offshore load factors were between 2,800 h/a closer to the coast and 3,600 h/a further away.

Intermittence of renewables Biomass is the only reliable renewable fuel for power generation with a potential for some load following. Run-of-river hydropower production is reasonably predictable and reliable but has a seasonal production pattern counter to the pattern of demand.

— While PV production follows in principle the daily demand pattern, it is very peaky during non-winter days. On 26 May 2017 at 13:00, a record high of 27 GW were fed into the grid, building up and back down to zero within 7 hours. Usually, about one third of PV production on balance is physically exported (driven by market mechanisms), mainly to Austria and Switzerland (which have large pump storage, though lower than Germany's) and to the Netherlands, serving also as transit to Italy and the UK respectively.

— The seasonal pattern of PV is much more pronounced than that of run-of-river hydro. Monthly production from PV in January 2017 was 0.9 TWh *vs.* 5.3 TWh in July 2017. PV from individual households is generally fed into the local low voltage system, whereas power from PV clusters is usually fed into the middle voltage system, both with repercussions for the power balance in the high voltage system. Individual households are starting to install individual power batteries/storage.[117] As of the end of 2014, about 10,000 batteries were installed in households with a capacity of about 40 MW.[118] They might bridge a few days of production for an individual household, saving the fees (for grid use and the EEG fee) included in the power price in the summer, but they are not a solution for the seasonal variation of PV feed-in.

— Pump storage in Germany has an installed capacity of about 6,300 MW,[119] plus 1,291 MW in Luxembourg and 1,804 MW in Austria, tied into the German grid. The overall full load duration of their water volume is about 6 hours (corresponding to 54 GWh). To illustrate, pump storage is capable of peak shaving of 10 GW (compared to 42 GW for PV and 52 GW for onshore wind) for 5 hours and re-delivering it for 5 hours. This is absolutely minor compared to the volumes of wind power which may be produced (or, eventually, not) on a daily basis, e.g., 30 GW over 24 hours equals 720 GWh, or roughly 15 times the total pump storage volume linked to the German grid – on just one windy day. For comparison the total working gas volume in German gas storage is 23 bcm or about 250 TWh at a GCV (Gross Calorific Value) of 11 kWh / m3.

— Wind patterns are reasonably predictable for up 48 hours in advance, so that large downwards variations can be covered by thermal fossil-fired power with a warm or even a cold start. Shorter-

[116] This is one reason, why there is little wind power in Bavaria and Baden Württemberg, another reason being the fear of negative impacts on tourism.
[117] Senec (2018): Press release.
[118] Wissenschaftliche Dienste des Bundestages, 23.1.2017, Entwicklung der Stromspeicherkapazität in Deutschland, p.11t
[119] Bundesnetzagentur (Feb. 2018): List of Powerplants in Germany.

term variations can be covered by power plants on the grid (and pump storage). All thermal plants (lignite, hard coal, oil, gas, CCGT) are capable of providing such flexibility. The quick-start capability of gas turbines is not needed in practice to follow wind patterns.

- Wind power production by neighbouring countries will not help to compensate for wind fading away. Most EU countries, certainly Germany and its western and eastern neighbours, are located in the west wind zone. Western wind directions dominate over eastern ones, all strong winds come from the west. Given the large amount of installed wind power capacity, strong wind in Germany is capable of compensating for weakening wind power production in its western neighbouring countries for some time. This would not work for Germany itself, as the installed wind power capacity in Poland is only 5.8 GW, with another 1.2 GW planned.[120] Wind power usually peaks pretty much at the same time throughout north-western Europe, so dealing with wind fluctuations is a common problem.
- There may also be substantial variations from year to year: from 2016 to 2017, there was a large increase in production, onshore wind from 66 TWh to 87 TWh, and offshore wind from 12 to 18 TWh. This was due to new capacity coming on stream and that full load was about 200 h/a higher in 2017 than in 2016. At the 2017 wind capacity of 56 GW, this corresponded to a difference of 11 TWh. No storage could compensate for such a volume. Covering it by demand-side management would be equivalent to closing down all primary aluminium production (about 7.5 TWh), plus other power-intensive industries in Germany for a year.
- Power-to-gas pilot plants so far have a total inlet capacity of 20 MW, less than 1/2000 of either installed PV or wind capacity. While in principle this approach offers an interesting solution to the storage and large-scale transportation problems, it still needs substantial upscaling and learning effects before it can be rolled out commercially. Though technology breakthroughs cannot be excluded, it will certainly take more than ten years before they are broadly applied. Until then, the intermittence of PV and wind can be compensated only with the use of thermal power capacity without jeopardising reliability of power supply. This was also a conclusion of the IEA country review of Germany in 2013.[121]

The profile of individual days in 2017 and at the beginning of 2018 shows the following general and specific patterns:[122]

- The variation of PV is similar to the variation in demand over the day. The remaining difference in the summer is typically modulated by an export surplus corresponding to 1/3 of the PV feed in and on a regular basis by modulation within the day provided simultaneously by hard coal and gas.
- In addition to the midday peak of net exports regularly there is another lower peak at night, when demand in Germany decreases faster than maintained thermal power production.
- Exports to Austria and Switzerland were frequent and reached up to 3 GW to each country; exports to the Netherlands were less frequent but reached up to 5 GW. Imports on a much smaller scale came from Norway, Sweden, Denmark, Poland, the Netherlands and France.
- Intermittence of wind (with little regularity) is followed by gas and hard coal simultaneously, with coal taking up a significantly larger part.[123] In extreme cases, lignite and, in exceptional cases, nuclear plants also take part in the modulation of wind feed-in, typically on weekends and holidays with low demand. When wind power decreases rapidly (in extreme cases by 2 GW/h),

[120] Wikipedia (Feb. 2018): Windpower in Poland.
[121] [121] IEA (2013): Energy Policies of IEA Countries, Germany 2013 review, p. 149.
[122] Frauenhofer Institut (Feb. 2018/2): Evaluation of electricity production in Germany in week 21 2017
[123] With a gas to coal ratio of 0.5 to 0.6 on a monthly basis and 0.5 to 0.7 on a weekly basis, with ratios below 0.5 over twelve weeks and ratios above 0.7 over six weeks. Gas produced more power than coal during only one week.

the necessary compensation can be provided by coal and gas-fired power, but also by lignite if lignite-fired production was reduced previously due to strong wind.

2017 and 2018 so far offered good examples illustrating the challenges of increasing wind production. Especially the first week of January 2018 saw quite a rollercoaster, when storm Burglind (Eleonor) passed through Germany: wind power feed-in was at 35 GW on 1 January, down to 16 GW on the 2nd, up again to 42 GW on the 3rd, down to 14 GW on the 4th, back to 38 GW in the morning of the 5th, and finally down to 3 GW on 6 January. Gas and coal were down to less than 2 GW each at times, and lignite and nuclear also took a substantial part in load following, as did net exports, which varied between zero and 15 GW. In particular, the following extreme situations occurred during that week:

- On 1 January 2018, renewables covered practically 100% of domestic demand, while on balance, all power produced from fossil fuels and nuclear was exported.
- On 3 January 2018, very strong wind faded within 7 hours. The necessary ramp-up of 20 GW was managed successfully.
- After a new peak of wind feed-in on 4 January, with a high of 38 GW of wind feed-in shortly after midnight on 5 January, most thermal power plants operated in partial load, some coal-fired plants with a warm shutdown. Wind power then dropped from 38.1 GW at 3:00 to 20.6 GW at 10:00 and further down to 10.2 GW at 17:00. Lignite was used for load following, first increasing from 4.5 GW at 3:00 and reaching 15.5 GW at 10:00 within 7 hours, or a 1.5 GW increase per hour. Gas and coal-fired power came in at 10:00, after lignite was coming close to capacity. Exports dropped from 14.77 GW at 3:00 to 8.62 GW at 10:00 and to 0.89 GW at 17:00. At 3:00 intraday prices were at minus 5.96 €/MWh, climbing to plus 30.31 €/MWh at 10:00 and then to plus 58.10 €/MWh at 17:00.The load following of 2 GW/h made necessary by the drop in wind force was shared according to merit order between lignite, hard coal and gas and the export/import balance triggered by merit order and market conditions. Gas did not play any specific role in it.

Similar patterns were observed, during the week of 15-22 January 2018, when storm Frederike passed through Germany. Other extreme examples are from 2017:

- week 40, which had strong wind and sunshine, and the sum of gas and coal feeding into the grid was below 8 GW, at times below 4 GW.
- There was also a longer period with low wind and little sun (*Dunkelflaute*) between 16 and 25 January 2017, when wind power generally was below 5 GW (with one or two days with up to 7 GW) and at times below 1 GW, while PV was low due to low sun in the winter.

While these situations could be handled by the existing grid and power plants and changing import/export patterns, they illustrate the upcoming challenges of the renewables targets under the new coalition agreement, requiring scaling up wind power by a factor of two and more.

Prices in 2017 In 2017, there were more occurrences of negative prices and higher negative values than in 2016 (but also much higher high prices). The priority to feed renewable power into the grid and the incentive to run nuclear and lignite as base load without much variation resulted in market conditions leading to longer periods of negative prices than in the years before.[124]

6.4 The future role of renewables

Setting renewables targets The share of renewables is affected by consumption patterns: the use of more efficient electric devices reduces consumption and the required renewable capacity, while sector coupling leads to consumption growth and more pressure on renewables to keep up.

Present rules define the share of renewables in gross electricity consumption at between 40% and 45% by 2025, and between 55% and 60% by 2035. The 2019 version of the Network Development Plan for

[124] Agora, 2018, Die Energiewende im Stromsektor: Stand der Dinge 2017, p. 38 and following.

2030 (*Netzentwicklungsplan*, or NEP) assumes a range of between 47.5% and 52.5% for 2030, derived by interpolation. The recent draft coalition agreement of 7 February 2018 signed on 14 March 2018 aims at a renewables share of 65% by 2030.[125] The *de facto* share of renewables was 31.7% in 2016 and 35% in 2017.[126,127]

A target of 65% renewables production by 2030 would be a substantial deviation from the present NEP for 2030 (version 2019) and from the ranges applicable so far. Even assuming constant gross electricity consumption, increasing renewables from the current 35% to 65% would translate into an extra production based on wind and PV of 209 TWh/a, corresponding to 145% of combined wind and PV production in 2017.[128] This would require installing some additional 60 GW in PV, 75 GW in onshore wind and 10 GW in offshore wind, resulting in a total of 110 GW of PV, 125 GW of onshore wind and 15 GW of offshore wind by 2030 (almost twice the amount assumed in NEP 2030, version 2019).

Renewables' share and decarbonisation targets The share of renewables depends on their capacity and on the wind harvest. The impact of renewables on decarbonisation in Germany varies largely depending on the variants discussed above but also on the export / import balance, resulting in a disconnect between the share of renewables and its effect on CO_2 emissions in Germany, so it is difficult to assess the impact of further increases in renewables on decarbonisation.

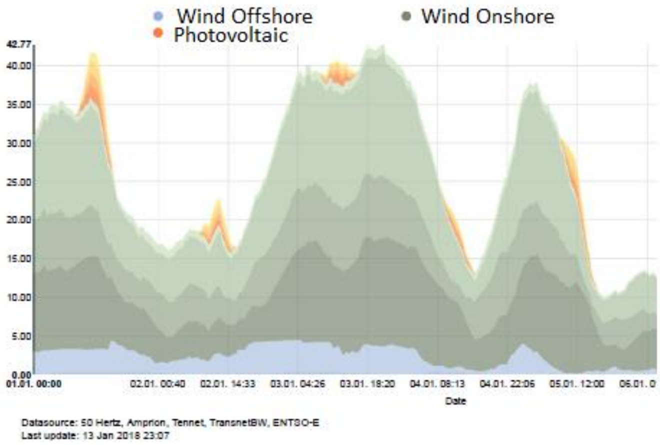
By way of illustration, replacing the share of remaining nuclear by renewables would meet the renewables target of 45% by 2025 (the upper range) but would not affect GHG emissions. Replacing nuclear by stopping net exports and increasing net imports would reduce German power production by 13%, without any change in CO_2 emissions. In that case increasing renewables production would *ceteris paribus* have a full effect on the reduction of carbon emissions. Increasing renewables will only reduce emissions to the extent not counteracted by corresponding export volumes of coal or lignite-based power.

In a scenario where production and exports remain at 2017 levels, a 65% share of renewables by 2030 would not just replace the 13% share of nuclear, but also some thermal generation. This would correspond to a reduction of between 90 mln t CO_2/a[129] and 120 mln t CO_2/a.[130] For Germany to reach the decarbonisation target of 560 mln t $CO_{2\,eq}$, a total gap of 340 mln t $CO_{2\,eq}$ per year needs to be closed by 2030. Beyond compensating for shutting down nuclear by 2022, a renewables share of 65% would contribute to closing this gap by between 25% and 35%. The remainder would need to be covered by other sectors.

Storage and DSM as flexibility instruments to compensate for intermittence of renewables No storage is capable of compensating for the variations in wind power for the next decade and beyond (*see* figure 14 below). The existing pump storage volume of 56 GWh can absorb about 1-2 hours of wind power or of midday PV power. Current battery solutions are capable of even less. Power-to-gas use is very limited so far, with about 20 MW of electrolysis run in test mode.

[125] Draft coalition agreement of 7 February 2018, line 3255.
[126] BMWi (Sep. 2017): Renewable Energy in Figures
[127] Frauenhofer Institut (March 2018): Electricity Generation in Germany 2017
[128] Hydro and biomass have reached their potential already, so they would not play a role in the proposed increase.
[129] If hard coal and gas-fired generation is reduced.
[130] If lignite-fired generation is reduced.

Figure 14: Intra Week Fluctuations of Renewable Power Production



Source: Frauenhofer (2018). Retreved from: https://www.energy-charts.de/

There might be some potential in electricity-intensive industry following a price-induced pattern, e.g., the aluminium smelter industry, given its overall demand of about 7.5 TWh/a. However, the savings potential of closing aluminium smelters is limited by their overall power inlet capacity of 1 GW. Heat pumps would be at the minimum of their efficiency on cold winter days, and with often low (eastern) wind, there is not much hope for using them to compensate for fading wind.

That leaves thermal power in Germany and adjacent countries to compensate for the fluctuations in wind and PV production.

6.5 Phasing out nuclear

The nuclear shutdown schedule is set by law: one reactor will be closed at the end of 2019, three more in 2021, and the final three in 2022. Two reactors are in each of Bavaria and Baden Württemberg; their closing will aggravate the already existing electricity grid bottlenecks between Northern and Southern Germany. The situation might by exacerbated further with the closing of France's oldest reactors in Fessenheim on the French side of the upper Rhine (2 x 880 MW), which will be shut down as soon as the new nuclear plant in Flamanville in Normandy starts operation (expected in 2020).[131] This will not alter the French capacity balance, but the north-south balance in the EU grid will be affected.

The German nuclear shutdown will have several impacts: (i) on decarbonisation (ii) on capacity adequacy (iii) on the export/import balance and (iv) on the north-south bottlenecks within the German power grid and possibility of re-dispatch.

The four issues are intertwined. Today's high exports come at the expense of reducing German CO_2 emissions. Renewables can replace CO_2-free nuclear, but extra renewables do not compensate for the loss of dispatchable power due to the nuclear shutdown, thus eating up the margin between dispatchable power and peak load in Germany. Additionally, renewables, wind in particular, do not necessarily come on-stream where demand is, raising issues for the grid. Replacing the nuclear production of 10 GW at 7,000 h/a solely with wind would require 30 GW at a load factor of 2,300 h/a. This would create many more situations with a need to push overproduction of wind into adjacent grids, while imports would be needed increasingly to compensate for the lack of dispatchable power. Current

[131]World Nuclear News (April 2017): French state moves to ensure Fessenheim closure.

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exports to Austria and Switzerland could be reversed after the closing of nuclear if no new adequate gas-fired capacity is built in the south of Germany.

By contrast, replacing Germany's nuclear production with gas-fired production would not increase the capacity adequacy problem. Nor would it add to the north-south grid bottleneck (if sufficient capacity is built in southern Germany), [132] at least by offering re-dispatch potential. The impact on carbon emissions would depend on utilisation factors of existing and eventually new gas-fired capacity, which could also improve without new gas-fired power. Additional gas-fired capacity would offer more potential to replace lignite and coal-fired power.

Grid planning partially fixed by law foresees several new HVDC north-south lines, mainly to transport wind power from the north (expanding the market for wind power). However, the lines will not be ready by 2022; a lead time of 10 years for finalising the construction of power lines is considered as quite ambitious. In the medium term, having extra gas-fired capacity in the south would open the opportunity to transport wind power as power-to-gas to the south via existing gas pipelines with plenty of capacity, while also using gas storage to mitigate the large variations in wind power harvest.[133] A description of the present grid planning process is given in Appendix 2.

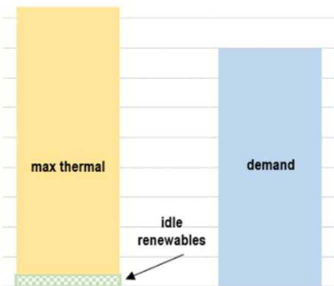
Dispatch of reliable power across Germany, especially after the closing of about 5 GW of nuclear in the south by the end of 2022, can hardly be addressed by scenarios for 2030 and underlying assumptions on capacity additions and market simulations.

Yet this is what the government is doing. Such an approach will not deliver solutions, certainly not to the problems that need solving by the end of 2022, risking either blackouts or having to maintain nuclear generation. This situation rather needs instruments to address the short to medium-term adequacy of capacity in Germany in cooperation with its neighbouring countries.

6.6 Renewables and generation adequacy

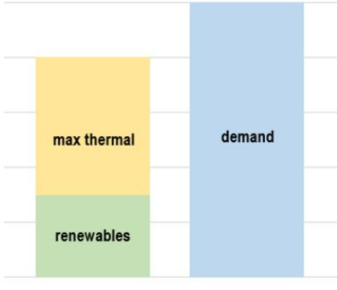
The analysis of impacts of renewables on generation adequacy yields several scenarios, presented below. They reflect the feed-in priority and the minimum capacity requirements for thermal plants on the grid, which have to be run for technical reasons (such as the minimum load of single plants or the minimum load for must-run CHPs).

Weak winds in dark winters (*Dunkelflaute*) are not problematic from a capacity point of view, as long as *dispatchable load covers peak load demand*. This is independent of installed renewables capacity, which will be idle whatever its size.

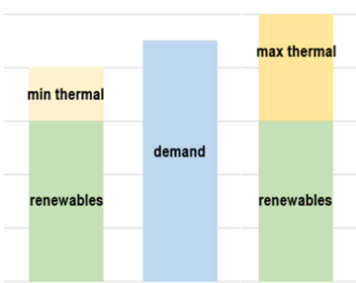


[132] Bayerischer Rundfunk (May 2017): Press release; The government of Bavaria has been promoting 2 GW of gas-fired reserve power, however only 1.2 GW were approved by the German regulator BNetzA in May 2017.
[133] FNB Gas (March 2018): Entwurf Netzentwicklungsplan Gas 2018-2028, p. 167 and following. This topic is discussed by gas TSOs

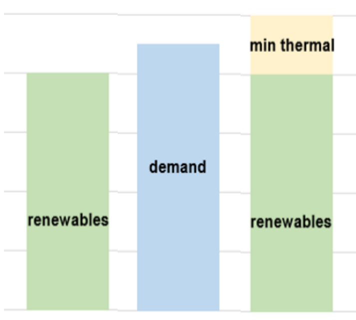
Feed-in by renewables plus maximum dispatchable thermal is lower than German demand. In this case, Germany depends on imports of reliable dispatchable power.



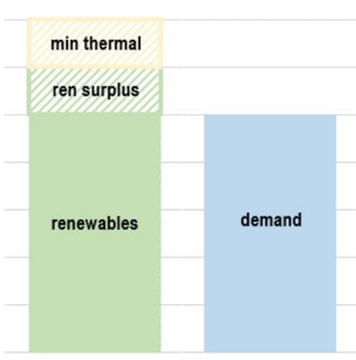
Renewables plus minimum thermal is lower than German demand, which is lower than renewables plus maximum thermal. In this case, there is no technical need for exports, the potential to export depends on commercial considerations.



Renewables are lower than German demand, which is lower than renewables plus minimum thermal. This case results in exports pushing power into adjacent grids, replacing thermal power above minimum capacity. However, strong wind usually occurs at the same time in Germany and in its neighbouring countries, and some of them have a high minimum thermal capacity, mainly nuclear in France. Increasing the load of thermal plants in the case of fading wind is adequate when every country has the potential to cover its own peak demand and can manage the ramp-up. Relying on the neighbours' spare dispatchable capacity will not work in stress times of quickly fading wind across north-western Europe.



*Renewables production is **equal or larger than** German demand*. If renewables supply is equal to domestic demand, e.g., on a weak demand day (like 1 January 2018), the minimum power of thermal plants has to be exported or will have to be shut down for a warm or cold restart. Renewables feed-in exceeding German demand will have to be capped and/or exported.



With the existing renewables targets (and even more so those proposed by the new coalition agreement), Germany's wind power capacity will be increased substantially and the renewables feed-in will often become much larger than domestic demand. This will lead to more days with exports of the minimum load from thermal, and increasingly Germany will be forced to push its wind and PV surplus into adjacent countries, like France, Belgium, the Netherlands or the UK (via the Netherlands). Alternatively, the surplus of renewables will have to be shut down.

Assuming manageable power covers peak demand, Germany can handle the fading away wind after a storm. In principle, this would also apply to adjacent countries. For adequacy, it does not matter if fading wind power has to be replaced in Germany or in other countries. Market prices (and grid bottlenecks) would decide where thermal production is to be displaced.

During storms like Frederike, grid connections permitting, Germany's neighbouring countries may have to expect an enormous surplus of wind power pushed by cheap prices into their grids. This will be followed by the need to compensate a steep fall in wind power, which in all likelihood could not be managed by German thermal power alone but will require thermal power plants in adjacent countries to operate in load following mode. The enlarged wind capacity in Germany will need an enlarged market area (including plants in load following), which will "swing" to the tune of German wind power.

The basic rule should be that each country should be able to cover its peak load by its own dispatchable capacity including a safety margin (thermal, plus hydro, plus biomass, plus nuclear, but at most the historic minimum of wind and PV capacity, if at all). In its most recent country reports, the IEA is very critical of the generation adequacy in the UK, Belgium, Germany and France.[134][135][136][137]The most recent IEA country review of the Netherlands (2014) confirms that "generation adequacy remains strong under the most ambitious medium-term scenario for expansion of variable renewables generation in the Netherlands." The same is stated for the robust dispatchable generation reserve by 2030.[138] By contrast, the coalition agreement of the Dutch government formed by Mark Rutte[139] in October 2017 promised to close all coal-fired power plants by 2030, including the three plants only completed in 2015; a policy driven more by green symbolism than by a rationale of decarbonisation, nor by responsibility for reliable power supply.

6.7 Conclusions from Chapter 6

Summary of facts on German targets for electricity Germany will meet its 2020 renewables target for power, but it will substantially miss its decarbonisation target of 40%. Phasing out nuclear is on track while keeping reliable power supply, but the big challenge is still ahead, when the last seven reactors are shut down by the end of 2022. While the share of renewables in power generation has increased substantially, this did not reduce production of coal and lignite power but resulted in large power exports. Since 2010, grid development has been driven by accommodating renewables; reliability of supply comes as a collateral, and decarbonisation as a hoped for by-product, leaving at risk the phaseout of nuclear by 2022.

For Germany, 2017 set a new record in gross electricity production from renewables with 210 TWh, or 33% of total production of 650 TWh. 2017 and the beginning of 2018 showed days with strong wind and strong volatility. While in January 2017, there was practically no PV nor wind for almost two weeks, on 1 January 2018, renewable production equalled domestic demand, heralding more power exports.

Power storage has a long distance to go to become a solution for volatility. All thermal power categories took part in load following, the mix determined by merit order. Even during periods with wildly fluctuating wind power, gas was in no way used preferentially for load following:[140] the narrative of the highly

[134] IEA (2012): IEA Country Review UK, p. 131.
[135] IEA (2013): IEA Country Review Germany, p. 149.
[136] IEA (2016/1): IEA Country Review France, p. 138.
[137] IEA (2016/2): IEA Country Review Belgium, p. 114.
[138] IEA (2014): IEA Country Review Netherlands, p. 94.
[139]Reuters (Oct. 2017): Dutch government: shut down all coal-fired power plants by 2030.
[140] Based on the evaluation of Frauenhofer Energy Charts, which give hourly values for feed-in by energy source, export/import, etc.

flexible CCGTs needed to complement intermittent renewables is technically wrong [141] and not supported by the facts.

Focusing only on renewables in power and not addressing thermal power will not automatically lead to reaching the decarbonisation target and will jeopardise reliability of supply for Germany and its neighbours. In the end, the resulting upcoming shortfall of dispatchable power may even throw into question the nuclear phaseout as fixed by law. With the closing of dispatchable capacity (nuclear – by law, conventional – due to market drivers) Germany will face an increasing gap between available dispatchable power and peak load, according to the NEP 2030. This gap cannot be filled with whatever extra capacity there is in wind and PV. Turning to neighbours for reliable power is not an option, as these countries are facing similar problems, as well as other country-specific problems.

Policy implications Major policy targets relating to power stated in the Energy Strategy are the nuclear phaseout, reliability of power supply (generation adequacy), decarbonisation and development of renewables (which are rather an instrument). The phasing out of nuclear is determined in detail by law, however, ramifications and the resulting conflicts with other policy targets were not discussed when the law was drafted or revised subsequently. Reliable power supply requires keeping enough dispatchable capacity to meet peak demand (not necessarily using it, especially not for exports), compensating for closed nuclear and coal and lignite-fired capacity. Decarbonisation through renewables is partly eaten up by the nuclear phaseout; it is also undermined if renewables trigger the export of lignite and coal-based power. Fuel switching needs an instrument, which would change the merit order to reflect carbon emissions, e.g., a tax or a floor on carbon prices, like the one introduced in the UK.

Generation adequacy For a long time to come, generation adequacy will not be able to rely on storage to adapt wind power to demand patterns. In Germany, adequacy of capacity can only come from thermal power: lignite, coal, gas, and fuel oil. With nuclear to be phased out by 2022, the opening supply gap should be compensated with extra gas-fired capacity, preferably located in the south of the country. Instruments, such as a capacity market or various managed reserves, should be put in place to ensure Germany has enough dispatchable power within its own borders. All thermal power plants could be used for load following, even older ones, retrofitted in line with the EU's Large Combustion Plant Directive. This is an economic issue, which also depends on the total price of CO_2 emissions. New gas-fired capacity would be better for decarbonisation as it could be run also at high load factor, when the merit order is right. It should be possible to transfer this new gas-fired capacity from a reserve to the normal market. Also with power-to-gas, which promises the largest potential for power storage, gas-fired power capacity is needed to re-transform the gas to power (in the south).

Germany should not force its neighbours to swing to the tune of German renewable wind and not eventually rely on them for dispatchable power. Coordination with neighbouring countries is a *conditio sine qua non*; the adequacy instruments should be coordinated for the phaseout of nuclear in 2021 and 2022 (and Fessenheim in 2020, and Belgium nuclear by 2025).

Decarbonisation In an open EU market and with the ETS as it is, higher shares of renewables, even if they go beyond replacing nuclear volumes, will not automatically contribute to further decarbonisation if extra volumes are in balance, provoking lignite or coal-fired power to be exported. To address this and to harvest the large CO_2 saving potential of switching to gas, a carbon surcharge should be introduced (in Germany at the national level, but also in the Netherlands, Belgium and France). This would result in higher gas consumption for power generation and in higher imports. In view of the working EU gas market and large LNG import capacity, this would not pose a security of supply risk,

[141] CCGTs do not have much better flexibility (higher load gradients) than modern coal-fired power plants; it is the steam turbine, which determines flexibility, and it is common to both technologies. Gas turbines are different, but rather by design than by fuel used, which can be clean fuels like LPG or clean gasoil or gas. While gas turbines have a very short start-up time, they have not played a role in load following so far.

especially if coal and lignite power is still in standby or backup mode. For pragmatic reasons, it appears best just to copy the UK carbon price floor, which would also help to avoid market distortions.

Chapter 7: Transport and Mobility

Transport-related GHG emissions in Germany have been rising over the past years, from 153 mln t CO_2 in 2010 to 166 mln t CO_2 in 2016,[142] reaching 18% of the country's total GHG emissions. Road transport accounted for 95% of all transport-related GHG emissions. The recent emissions hike is the result of higher volumes of truck and car traffic, as well as a slight reduction in the use of biofuels in transport.

Petrol and diesel are blended with biofuels by up to 10%, limiting the role of renewables in transport. Natural gas so far plays a very limited role as a transport fuel in Germany: out of 55 mln vehicles on the road,[143] less than 100,000,[144] or about 0.2%, are CNG-driven vehicles. LPG is the most widespread alternative fuel for motor vehicles, with 450,000 LPG-driven vehicles in 2017.

The forecasts in IEA scenarios for natural gas-run vehicles range between 31 mln and 186 mln worldwide by 2035.[145] A policy shift promoting gas cars could have a significant impact on gas consumption, although the current trends and policies in Germany do not point in this direction. The taxation privilege for gas fuels will be reduced from 2018 on. The current crisis of diesel cars might contribute to a shift towards a more gas-friendly policy in transport and lead to a surge in gas-run cars, but so far there is not much indication of such a move.

While LNG could be attractive as a fuel for heavy-duty vehicles and for inland freight ships, it is difficult to find pilot projects. Such pilot projects should be easy to promote by the gas industry granting an introductory rebate, large enough to pay for the amortisation of switching to LNG within a few years. This would amount to a system of replacement value minus an introductory rebate, which was the way the gas industry started in the 1960s. Given the debate on particulates and NO_x emissions in cities, promoting such projects should be not too difficult.

The main issue remains: what will happen with light-duty vehicles? As of December 2017, a total of only 129,246 plug-in electric cars were registered in Germany.[146] This is still far off the German government's target of bringing 1 mln electric cars on the road by 2020. In addition to the missing infrastructure, the main open issues are the limited reach and long recharging times of e-cars. Hydrogen/fuel cell driven cars have not made much progress either, even though commercial car models offer a reach of 600 km with a fuelling time of 5 minutes. Currently, there are only a few hundred fuel cell cars in Germany, and the number of hydrogen gas stations, while supposed to grow from 56 in 2017 to 100 by 2019, is much too low to make hydrogen fuelled cars attractive. With costs of about €2 for 1 kg of hydrogen produced by gas reforming and fuel cell car series models presently entering the market with a normal use of less than 1 kg/100 km,[147] hydrogen car sales could take off over the next decade. However, in Germany, they will hardly become anywhere near significant before the 2030s, due to the lack of fuelling stations and in general due to the inertia of the car industry.[148] Parts of the transport sector, particularly air transport and ships, will have to be run on hydrogen from the middle of the 21st century, if the vision of an almost GHG-free economy is to be realised. Fuel cells are certainly a central technology for the

[142] BMUB (March 2017): Climate Protection in Numbers. See chart of CO^2 emissions in traffic.
[143] Statista (Feb. 2018): Number of Motor Vehicles in Germany 2005-2018.
[144] Gib Gas (2018): Statistics on Gas run Vehicles.
[145] Shell (2013): Natural Gas a bridgetechnology for the mobility of the future.
[146] Wikipedia (Jan. 2018): Electric car use by country.
[147] Focus (2018): Hydrogen Hybrid with 1000 km Range.
[148] FAZ (Feb. 2018): In the End Hydrogen Cars Will Succeed..

future. The question of decarbonisation of natural gas has to be considered and discussed also in this context.

Coalition agreement of 14 March 2018 The draft new coalition agreement of the German government of 7 February 2018 signed on 14 March 2018 does not contain any specific instrument to ensure GHG reductions in the transport sector. Its instruments are limited to subsidies, mainly for electric but also hydrogen cars, and support of the public transportation sector. The decisive tool of fuel taxation stays untouched under the present agreement, a lost chance to foster climate-friendly modes of transport and to raise the direct taxation of GHG emissions in times of relatively low oil prices.

The coalition agreement announces that the leading principle for the German Railway (Deutsche Bahn) from now on should be to maximise the number of passengers, with the goal of doubling the number of passengers by 2030. Another goal is to reach the share of 70% of electrified routes by 2025. It is also declared that more effort should be undertaken to support freight rail transport. While these announcements sound very useful for reaching a reduction of GHG emissions in the transport sector, it remains unclear how they are going to be financed and implemented.[149] It remains to be seen how serious they are, but a switch in the mode of transport will lead to a far higher reduction of GHGs than switching fuels in transport.

In any case, the share of road transport will stay dominant (currently well above 80% of passenger and freight transport)[150] and economical climate-friendly solutions for the future remain to be found. The expected slow reduction in GHG emissions in the transport sector is a major obstacle to reaching the overall GHG reduction targets.

Conclusions on transport and mobility Reducing GHG emissions from the traffic sector is a major stumbling block on the way to achieving decarbonisation on a scale intended by the German government. At the same time, after a decision on 27 February 2018 by the highest public law court (*Bundesverwaltungsgericht*), which allowed individual cities with high NO_x pollution to bar parts of the city to diesel cars, there should be a stimulus at least for LNG in trucks. For light-duty vehicles, the vision of all-electric transportation still looks bleak, unless new-technology cars become more customer-friendly. At the moment, hydrogen-driven cars look like the more customer-friendly alternative, but this technology is held back by the lack of filling stations. The gas industry and the government should promote fuel cell cars based on hydrogen from decarbonised natural gas as a way to decarbonise the transport sector, as an alternative or a complement to plug-in e-cars, should they not live up to expectations.

Chapter 8: Conclusions

The German government, which justifiably claims a pioneering international role in decarbonisation, has rather been following a much-needed renewable policy instead, substituting the instrument for the target. While meeting its own renewables targets for 2020 (35% renewables in domestic power consumption), the country will fall substantially short of its decarbonisation target of 40% by 2020, achieving only 30%. The German experience suggests two major lessons:

I. In view of the time constraint given by the carbon budget, renewables alone facing problems both on the supply and on the customer side will not deliver in time the required decarbonisation. Decarbonised gas can and should be a complement and competitor to renewables to meet the targets of the Paris Agreement. The gas industry should explore and invest in promoting decarbonised gas, and governments should foster gas competition with renewables by setting an appropriate framework.

[149] Bundesregierung (March 2018): Coalition Agreement) by SPD/CDU/CSU.
[150] Based on 2010 figures and the latest development of different modes of transport in Germany.

II. There is a large policy overlap between the ETS applied to the power sector at the EU level and the ambitious German renewables policy, with major impacts on the German and EU power sectors. Policies to implement the Paris Agreement should start with the target of decarbonisation to enable a rational approach to trade-offs between policy targets and to address the possible overlap and conflict between policy instruments and find the appropriate instrument mix. Even though fostering renewables was and is a necessary tool, the contribution of other tools should not be discarded, such as reducing the carbon intensity of fossil fuels through fuel switching and promoting decarbonised natural gas as a carbon free alternative to renewables. This requires a refocus on the target of decarbonization.

8.1 Lessons from Germany on the role of gas and renewables in decarbonisation

Germany's experience of course cannot be applied directly to other countries. However, it does suggest some principal issues for renewables, both on the supply side and on the demand side.

Limitations of a renewables approach on the supply side The German example shows the limitations of the development and deployment of renewables: biomass production is in conflict with food production and limited by the decarbonising role of biomass sources absorbing CO_2 from the atmosphere. Therefore the focus now is on electric renewables only. Hydro and geothermal may have potential in some countries, but they can substantially contribute to total energy demand only in mountainous countries with a small population such as Norway or Iceland. That leaves PV and wind.

PV comes with a large variation over the day everywhere. Closer to the equator, that may be compensated with daily electricity storage, but the strong seasonal variation in the northern hemisphere cannot be covered by storage.

Wind has the largest potential, but is erratic, even though reasonably predictable over 48 hours. This raises the question of how to adapt in the short-term to long-term unpredictable and substantial changes in wind, strong seasonal variations and the difference between strong and weak wind years.

Relying on renewable electricity as the predominant source of power requires figuring out how to store large volumes of electricity. The most realistic but still distant solution is to transform surplus renewable power into hydrogen by electrolysis and to adopt the existing natural gas infrastructure to handle hydrogen.

Problems with electric renewables on the demand side and the potential of gas Obstacles are not only on the supply side of renewable electricity, but also on the consumption side (e.g. by sector coupling*:*

- In buildings: energy efficiency and insulation figures lag behind the announced targets, especially for refurbishment of the energy efficiency of the existing building stock, which will remain the dominant share of buildings in 2050. Renewables in buildings so far are mainly biomass (firewood) and solar thermal with little extra potential, and heat pumps, which have further potential but are not suitable for multi-storey buildings in cities. Additionally, their efficiency decreases in the winter, adding to peak winter demand for power capacity, which has to be covered by dispatchable power.
- Gas use has been going down due to better insulation and the mandatory use of renewables in new houses. However, this decline may be compensated by replacing old oil boilers and using more gas in CHP plants. In the longer run, introducing hydrogen, blended for use in existing gas boilers would allow the continuing use of existing gas distribution grids, and also heating appliances and installations.
- In industry most of the energy consumption is process heat and electricity, self-generated or from the grid. Renewables will continue to play a minor role in the form of waste from processes using biomass. Also the future potential of using cheap surplus electricity from renewables looks limited.

- There is still a substantial share of coal to be replaced by gas and a substantial potential for more CHP run on gas. As the role of renewables is limited, use of hydrogen or ammonia from decarbonised natural gas looks like the major way to decarbonize energy use in industry.
- Transport is dominated by the use of liquid fuels. Gas-based liquid fuels in trucks (e.g., LNG) should have a large potential, as trucks will not run on batteries. The big issue for the future is plug-in cars vs. fuel cell cars. The comfort of existing ready-to-buy models is more with the fuel cell car. However, the number of hydrogen filling stations in Germany is very limited, while there is much public attention to plug-in e-cars, wrongly identified as the only carbon-free solution in road transport.

Decarbonising natural gas as a GHG-free alternative Reaching the target of the Paris Agreement of keeping the rise of global temperatures below 2 degrees Celsius or less requires keeping within the remaining carbon budget of about 1,000 GT of CO_2. Given the problems showing up in Germany, a pioneer country of de-carbonization dedicated to develop renewables, of focussing on renewables to meet the de-carbonisation targets, it is difficult to envisage that renewables will grow fast enough to provide a carbon-free (and then sustainable) energy supply for all sectors worldwide within the time frame given by the carbon budget.

It is therefore mandatory to develop GHG-free alternatives to complement the role of renewables. In this context it is important not to fall into the trap of equating carbon-free energy with sustainable energy (i.e. renewables). Decarbonised hydrocarbons, mainly decarbonised natural gas, have a large potential to add to GHG-free energy supply within the limits of remaining hydro carbon resources. Decarbonising natural gas to carbon-free hydrogen, can add another carbon-free energy supply competing with renewables, which can be better adapted to use in buildings, industry and transport.

The main issue of decarbonisation of natural gas is the disposal of the CO_2 created through any decarbonisation process of hydro-carbons. Pre-combustion decarbonisation by a reforming process holds the advantage that the CO_2 can be separated all along the chain and is not diluted by N_2 as in a post-combustion process. The CO_2 can then be reinjected into any geological structure along the chain, best into the producing reservoir, where it would exchange CH_4 for CO_2, one-to-one. To a large extent, the resulting H_2 can use the adapted existing gas infrastructure, pipelines, storage and the distribution grid and appliances in households. In addition, it opens up a GHG-free use in fuel cell cars. While this would require a system change, switching to hydrogen looks less problematic and more feasible than introducing an all-electric system – cost-wise, but also with regard to effectiveness and the time scale. Such a system would be based on the technology already applied in ammonia production on a large scale. Hydrogen pipelines are already in operation on an industrial scale, e.g., between chemical factories, and distribution grids in many countries used to transport town gas, which was 60% hydrogen, before natural gas took over, so the conversion being discussed is technically feasible. Transforming the existing natural gas system into a hydrogen system would also pave the way for transporting and storing hydrogen from surplus electricity via electrolysis.

The size of the remaining gas reserves and unexplored resources would allow using the transformed hydrogen system for several decades, meaning that it would offer itself to commercial investment with little risk of stranded investment. In fact, by decarbonising natural gas, the lifetime of the gas exploring and producing industry might be much the same as without decarbonisation (and the PA). Instead of producing gas whose CO_2 is emitted into the atmosphere, it would produce gas whose CO_2 is reinjected into upstream geological structures. For the gas infrastructure industry (transportation, distribution and storage), some changes would be required for the conversion to hydrogen. This should be possible and would maintain the value of the main assets of the infrastructure industry and the customers' appliances. Last but not least, decarbonising natural gas would maintain the value of the hydrocarbon reserves of gas exporting countries.

The gas industry will have to deliver a decarbonised product in competition with renewable electricity, but a product which will be more flexible in its supply and its applications and which will be reflected in the price. Gas would not be a fuel to bridge the time until a decarbonised world is achieved but would become part of the decarbonised world until recoverable gas resources are depleted or renewables can take over, being more competitive. However, there must be joint action by industry and government and by exporting and importing countries to help the change to a competitive hydrogen system.

8.2 Challenge of Germany's decarbonisation policy

Germany's decarbonisation policy has been effectively substituted by a policy promoting renewables. The result: the renewables policy will meet its 2020 goals, while decarbonisation will fail blatantly. Alternative or complementary approaches to decarbonisation, such as fuel switching or decarbonising natural gas, did not come up in the discussion. Because renewables are equated with decarbonisation, conflicts and trade-offs with other instruments such as nuclear, fuel switching, and carbon pricing cannot be balanced against each other with a view to de-carbonisation.

Conflicts of renewables policy with other policy targets and other decarbonisation instruments
Renewables are in conflict with the target of reliability of supply:

I. bringing more renewables to the grid comes with an illusion that peak demand can be covered at least partially by non-dispatchable power. This has been proven wrong by periods of low wind and no sun, as during the second half of January 2017. Covering peak demand reliably requires the respective capacity of dispatchable power plus a safety margin as highlighted in the IEA country report on Germany of 2013.

II. Strong variations of wind may be combined with PV variation over the day, creating strong capacity gradients, which need all installed dispatchable capacity in load following. So far, this has proved manageable. When further increasing wind and PV capacity, Germany increasingly forces power in neighbouring countries to swing to the tune of wind in Germany. Cross-border cooperation will be needed, for which no instruments exist so far.

III. More renewables create conflicts with bottlenecks in the present grid configuration.

Another conflict is with the phaseout of nuclear by 2022, fixed in 2011 by law. With the lack of sufficient electricity storage, the accelerated deployment of renewables as envisaged in the recent coalition agreement may not be enough to meet the decarbonisation targets and will jeopardise the target of reliability of power supply. To the extent renewables have to compensate for CO_2-free nuclear production, they cannot contribute to decarbonisation.

Overlap of policy instruments of the EU and Germany Decarbonisation policy instruments for buildings, transport and industry usually take the form of support in one way or another, but do not contain penalty mechanisms to internalise the negative effects of GHGs. As this paper has demonstrated, they have all run into restrictions and have limited further potential.

The main instrument for decarbonisation – fostering electric renewables – strongly interacts with the defunct ETS, raising questions about policy effectiveness and efficiency. About 45% of GHG emissions in the EU are dealt with by the ETS (the power and heat sector and the largest industry emitters). This is EU policy, which is not under specific German influence. Free allocation of EUAs may be an instrument to keep industry in Germany, but it does not have an impact on emissions. Germany's renewables policy lowers demand for EUAs, thereby depressing their price, already dampened by lasting oversupply. Until the ETS becomes more ambitious, it will keep the merit order frozen to the benefit of coal/lignite and to the detriment of gas; fuel switching for decarbonisation will be barred. This way, German renewables policy risks hampering the functioning of the ETS, as well as reaching the German decarbonisation targets.

This could be overcome by using a nationally available instrument like an extra tax or a carbon floor such as in the UK, paid by EUAs to be withdrawn from the ETS market (as was originally proposed to overcome the deficit in decarbonisation, highlighted by the First Progress Report on the new Energy Strategy). This is also suggested by the modelling assumptions in the NEP for power, see Appendix 2.

The most pragmatic approach would be to follow the UK example of a carbon floor, if possible, together with neighbouring countries.

The implementation of the German decarbonisation policy certainly needs a reality check.

Appendix 1: Development of German legislation

A 1990 Feed-in Law for Renewable Power was used as the basis for the 2000 Law on Renewables (*Erneuerbare Energien Gesetz*, or EEG). The law provided for a priority feed-in, promoting renewables by setting feed-in tariffs on a technology-specific cost recovery level,[151] which were raised through a levy on electricity, the *EEG Umlage*. This law became the backbone of legislation on GHG reduction. It was amended/revised in 2004, 2009, 2012, 2013, 2014, 2016 and 2017, providing ever more details on feed-in tariffs and flexible feed-in volumes and introducing more market-driven mechanisms, such as auctions. It became the instrument of choice for raising more money for renewables via a fee, which was not a tax nor a burden on the budget, but rather worked like a special budget of substantial size, now at ca 20 bln €/a. In April 2002, it was supplemented by a law securing the feed-in of cogenerated power (*Kraft Wärme Kopplungsgesetz*, or KWKG). Due to the ecological benefits of CHP, its power output enjoyed priority over conventional electricity since 2000. The 2002 KWKG was overhauled in 2008 and was amended several times thereafter, the latest version effective as of 1 January 2017. It is designed to boost the ecological transformation of the fossil-fuel sector and supports CHP with substantial aid at more than €1 bln in 2016 and 2017. The estimate for 2018 is about €1.25 bln, which is below the annual ceiling of €1.5 bln.[152]

In 2008, a law on renewable energy in the heating sector (*EEWärmeG Gesetz zur Förderung Erneuerbarer Energien im Wärmebereich*) was added.

The new Energy Strategy of 2010 defined detailed decennial targets for most dimensions, first of all, for decarbonisation: a reduction of 40% by 2020, 55% by 2030, 70% by 2040 and 80% to 95% by 2050. However, these figures were not broken down by sector, and there were no overarching instruments for the total decarbonisation target, nor for sectoral targets suitable for steering such a process. The resulting plethora of proposed measures risks creating entry points for lobbying and policy conflicts within and between the objectives and chosen instruments.

The implications of the nuclear phaseout law had not been addressed before 2010, the new Energy Concept now raised the issue of grid design as a function of renewables deployment. The procedures for power grid planning were guided by phasing in renewables, not by minimising CO_2 emissions, which obviously could not be influenced by grid design. The target of reliable power supply also was lost in this procedure, sacrificed to emphasise the increase in renewables as the only available policy instrument for decarbonisation.

After the Fukushima disaster in March 2011, the prolongation of the nuclear phaseout was revised back to the original scheme, otherwise the Energy Concept remained unchanged. No additional policy measure compensated for the loss of CO_2-free nuclear generation of about 1500 TWh[153] nor for the loss of income from it – a major policy mistake according to experts commenting on the Monitoring Report presented to parliament each December.[154] In 2011, a triannual progress report was introduced to discuss the progress and possible adjustments to the Energy Concept, in addition to the existing monitoring process.

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[151] Before that, remuneration was derived from costs of displaced electricity production.

[152] Prognose der KWKG Umlage 2018, Stand 25.10.2017, at: https://www.netztransparenz.de/KWKG/KWKG-Umlagen-Uebersicht/KWKG-Umlage-2018

[153] Estimated as: 12 years extension x 20 GW x 6500 h/a = 1500 TWh.

[154] Expert committee for the Energy Transition (dec. 2016): Comment on the 5. Energy Transition Report, p. 13. p. 13.

Appendix 2 The German power grid planning process and de-carbonisation

The role of the German power grid is to serve as a market place paid for by its users through regulated fees. Regarding renewables, the grid is clearly intended to serve also as a tool to market ever more renewable power (as determined by policy targets). At the same time, the tasks of reaching the decarbonisation targets and reliable supply to German customers are left to the ETS and the EU power market.[155] This is reflected in the features of the NEP as an analytical tool for grid development strategy.

While the grid is regulated by a public authority (BNetzA) and the development of renewables is strongly influenced by government targets implemented through incentives for renewables, the government mainly leaves the availability and development of adequate dispatchable power capacity to the EU power market. However, the German government has instruments, accepted by the EU, to address the provision of reserve capacity.[156] They foresee various reserve categories, such as including a reserve of old lignite power plants and the building of new gas-fired power plants in the coming years.e.g.in Southern Germany to compensate for the capacity of the nuclear plants to be shut down.

Plants in the reserve category will be barred from bidding in the normal power market and will be mobilised by the TSOs when approaching tight situations. Various mechanisms address covering the costs of such reserve capacity. In the end, they will be added to the EEG fee, charged to electricity consumers. With regard to GHG emissions, it is certainly reasonable to put old lignite plants into a reserve, which will hardly be mobilised, if only for a few hours a year. This logic does not apply for newly built gas-fired plants.

Grid planning and future renewables generation capacity The priority treatment of renewables, mainly wind, is reflected in the Network Development Plan process, designed in 2010 in the context of the Energy Concept. The NEP (Netzentwicklungsplan =Network Development Plan), which looks at the requirements for the grid ten to fifteen years ahead, is an instrument of strategic planning. This should be distinguished from adequacy considerations, which look at challenges facing the existing grid up to six years ahead, and from the discussion of power capacity adequacy at the ENTSO-E level, also looking at 2030.

The NEP includes scenarios reflecting various pathways for renewables, as defined by policy. The latest NEP for 2030 (version 2019) includes scenario A 2030 – modest development, mainly ‘business as usual’; scenario B 2030 – medium ambitions for renewables and decarbonisation; scenario B 2035 – to proof the B 2030 scenario against structural breaks; and an ambitious renewables scenario C 2030. The NEP also has to include assumptions on an increasingly decarbonised electricity sector in line with the overall decarbonisation targets broken down to the electricity sector. The approach chosen by the TSOs after public consultations is subject to approval by BNetzA. It also includes assumptions on the demand side, differentiated by scenario, mainly by the speed of so-called sector coupling, like the development of e-cars and heat pumps, but also of power-to-heat, power-to-gas, etc. On the supply side, it looks at additions and withdrawals of thermal capacity. With that approach and based on the external price assumptions taken from the WEO 2017 market simulations are run on an hourly basis.

[155] Paying for a grid designed to accommodate renewables independently of national economic criteria reminds of Germany’s policy to keep (deep) mining operations in the country as a showcase for the German industry for mining equipment.

[156] Various earlier rules on reserve capacity are compiled in §13 of the EnWG since 29 July 2016. “Within the scope of the amendments to the EnWG, the Electricity Market Act envisages the establishment of various reserve power reserve mechanisms, so that there are always enough power plants available that can step in if there is not enough electricity available in the market to meet the electricity demand. These mechanisms are in particular the network reserve (§13d), the reserve capacity (§13e), the readiness of lignite-fired power plants (§13g) and grid stability systems (§13k)”. The draft of the new Electricity Market Act was adopted by the Bundestag on 23 June 2016 with some stipulations and announced on 29 July in the Federal Law Gazette.

The grid(s) of the future would have than to meet the n-1 Criterion (safely handling the failure of the largest component) for each hour, assuming temperature and wind conditions experienced in a critical year like 2012.[157]

While the NEP is a reasonable exercise, it is complex and, in the end, a modelling exercise not to be confused with real developments with or without government influence. There is also a danger that responsibility for public goods like decarbonisation and reliability of supply are projected onto grid operators, who only have the instruments to deal with the grid, but not with generation.[158] The NEP's approach of making sure the grid can handle the increased renewables output is reasonable. However, it raises several questions:

(i) First of all, with regard to decarbonisation: how to make sure the effects of modelling assumptions on decarbonisation can be achieved in reality?

(ii) (What is the outcome regarding reliability of power supply?

(iii) What is the impact of Germany's central role in the EU grid with regard to imports/exports, decarbonisation targets and reliability of supply?

Realising decarbonisation modelling assumptions For the NEP 2030, version 2019, the TSOs chose (after public consultations) the approach of tightening CO_2 certificates.[159] This will result in higher CO_2 prices at the national level (for the power sector), as a modelling assumption. This will lead to fuel switching, significant enough for meeting the decarbonisation targets set for the power sector (in the model calculations). This approach also will change the import/export balance as a contribution to decarbonising the power sector in Germany.

The model's parameter for achieving the decarbonisation targets in real politics could become a steering instrument in real life. This could be either an extra tax on CO_2 emissions by power plants[160] or a high enough carbon floor, as recently introduced by the UK. Such an approach would have a substantial impact on gas use in power generation, though it is not detailed in the NEP 2030 (2019). While keeping lignite and hard coal capacity as suggested by the NEP 2030 (2019) their share in power generation would reduce at least by half to 12% and 7.5% respectively, probably even more in view of the decarbonisation target. At least 15% would have to be covered by gas, compared to 8.5% in 2017, even in the case of 65% renewables, not yet addressed by the NEP. This indicates that gas use in power generation would at least double if the decarbonisation target should be met, even in the very optimistic scenario of 65% renewables.

While the resulting modelled grid (or several grids) will meet the scenario assumptions, it is unclear whether such scenarios will ever be realised and whether the real market and new installed capacity will be in line with the simulations. Concerns are even higher whether reliability of supply can be guaranteed; this is already a problem in the model calculations, even before addressing the 65% renewables share.

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[157] Bundesnetzagentur (jan. 2017): Grid development strategy 2030, 2017 version, p. 136: "The Network Development Plan 2030, Version 2017 (NEP 2030) represents the conversion and expansion of the German onshore electricity transport network against the background of the legal requirements of the Energy Industry Act (§12a-d EnWG). The transmission system operators (TSOs) plan, develop and build the network of Future. With the NEP they show how the conversion of the generation landscape in Germany and the integration of renewable energies can succeed until 2030 and 2035. "

[158] Except maybe within §13 EnWG dealing with all kinds of capacity reserves.

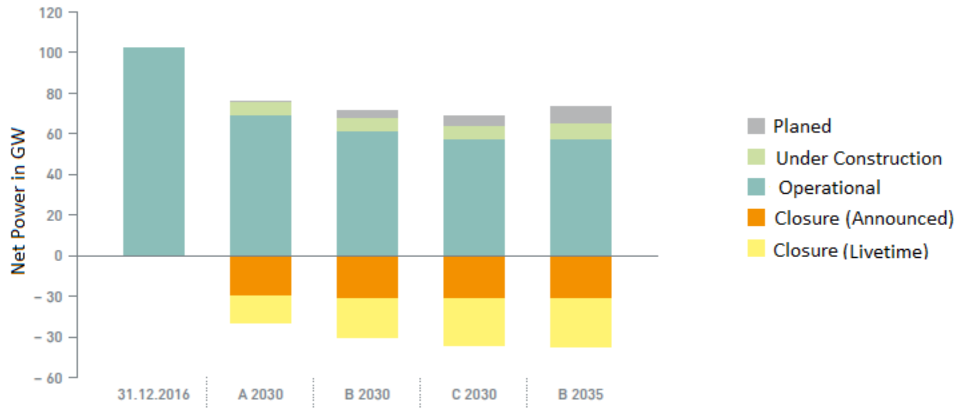
[159] Bundesnetzagentur (Jan. 2018): Grid development strategy 2030, 2019 version, p. 29.

[160] Already suggested in Germany in 2015 in view of the gap highlighted by the first review report on the Energy Concept but then replaced by the lignite reserve of 2300 MW.

Reliability of power supply outcomes Reliability of power supply appears to be becoming more problematic. The three scenarios have different approaches to the lifetime of thermal power plants, apart from nuclear (where the end of operation is fixed by law). All scenarios assume an increase in power consumption in volume, as well as in maximum load due to the addition of e-cars and heat pumps, modest in scenario A, optimistic in scenario B and extremely optimistic in scenario C. At the same time, the model assigns some load-reducing potential to e-cars and heat pumps.

Figure 15[161] shows the development of thermal capacity in the scenarios: about 20 GW are announced to be closed (the numbering on the vertical axis is wrong, it should be -20 and -40). Of these, 10 GW are nuclear in accordance with the law, and the other 10 GW are on the list of power plants scheduled for shutdown.[162] Depending on the scenario, between 10 GW and 20 GW of capacity are assumed to be shut down in addition by future decisions.

Figure 15: Development of Conventional Power Plant Capacity under the different Scenarios



Source: ÜNB, Szenariorahmen für den Netzentwicklungsplan Strom 2030 (Version 2019) P. 89

For lignite, no additions are assumed, instead, substantial closures are assumed. For hard coal, some small capacity additions are assumed, however, shutdowns are assumed on an even larger scale than for lignite. There are practically no assumptions on closing gas-fired plants, in fact, an addition of 7 GW to 13 GW is considered, depending on the scenario. As long as there is no remuneration by the market or some regulated remuneration for keeping capacity available, the modelled high carbon price will lead to low use of older lignite and coal-fired power plants and therefore their closing without adding new capacity.

The closing down of thermal power without replacement by new thermal power (an economic question, not a GHG question, in view of few hours of operation) leads to large deficits between the national maximum load and nationally available capacity, as shown in Table 4.[163]

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[161] Bundesnetzagentur (Jan. 2018): Grid development strategy 2030, 2019 version,) p.87.
[162] Bundesnetzagentur (Nov. 2017)*:* List to register power plants to be closed.
[163] Bundesnetzagentur (Jan. 2018): Grid development strategy 2030, 2019 version, p. 97.

Table 4: Thermal Powerplant Capacity in Germany

Scenario	A (2030)	B (2030)	C (2030)	B (2035)
Available power including reserve power plants	**78.9 GW**	**74.5 GW**	**71.8 GW**	**75.6 GW**
Reserve for system services	3.6 GW	3.6 GW	3.6 GW	3.6 GW
Secured performance including reserve power plants	**75.3 GW**	**70.9 GW**	**68.2 GW**	**72.0 GW**
Annual peak load	91.8 GW	96.9 GW	100.0 GW	98.8 GW
Of which transmission grid losses	1.8 GW	1.9 GW	2.0 GW	1.9 GW
Available load reduction potential	2.0 GW	4.0 GW	6.0 GW	5.0 GW
Peak load reduced by load reduction potential	**89.8 GW**	**92.9 GW**	**94.0 GW**	**93.9 GW**
Remaining performance	**-14.5 GW**	**-22.0 GW**	**-25.8 GW**	**21.9 GW**
Theoretical maximum available import capacity*	**42.0 GW**	**42.0 GW**	**42.0 GW**	**45.0 GW**
Theoretical maximum available export capacity*	**39.0 GW**	**39.0 GW**	**39.0 GW**	**43.0 GW**

* Particularly at the time of high electricity demand, it can be assumed that the actual exchange opportunities with foreign countries are significantly reduced and less than the theoretical maximum value.

Source: Uebertragungsnetzbetreiber

The first three columns of numbers in Table 4 give results for 2030 for Scenarios A, B, and C. The final column is for Scenario B in 2035.

The TSOs conclude that even without a more detailed analysis, it is clear that German conventional power alone will not be able to cover the residual peak demand load in any of the scenarios. In situations of strong load, this results in a substantial need for renewable power, imports or load management. However, the assumed remaining capacity is not sufficient for covering the annual maximum load, even considering renewables production and the load-reducing potential in industry through demand-side management. Under severe conditions, the resulting gap of between 14.5 GW and 25.8 GW is critical – not regarding the import capacity of the grid of 42 GW by 2030, but regarding the availability of reliable power import capacity. This should be subject to a detailed analysis.[164]

Impact of Germany's central role in the EU grid Common sense dictates that Germany's neighbours, even if they wanted to,[165] would not be able to close the gap of reliable power. So far, Germany often has been exporting extra capacity to neighbouring countries in severe winter situations.[166] If no measures are taken, this situation will have to be reversed. However, neighbouring countries have similar problems with installing substantial volumes of renewables, mainly wind and PV, and mastering specific challenges of their own. The IEA in its most recent country reports is very critical of the generation adequacy for the next years in Germany, France, Belgium, and the UK, though not in the Netherlands[167], but that was before the decision to close all coal-fired power in the Netherlands by 2030.

In the longer run, by 2030, some countries such as France and Switzerland will face the further ageing of their nuclear fleet. While Belgium and the UK will have shut down substantial nuclear capacity, countries like the UK and Poland also will have to close non-retrofitted coal-fired capacity in line with

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[164] ÜNB; (Jan 2018)Scenarios for the power grid development plan (NEP)for 2030 (draft 2019 version), p. 98.

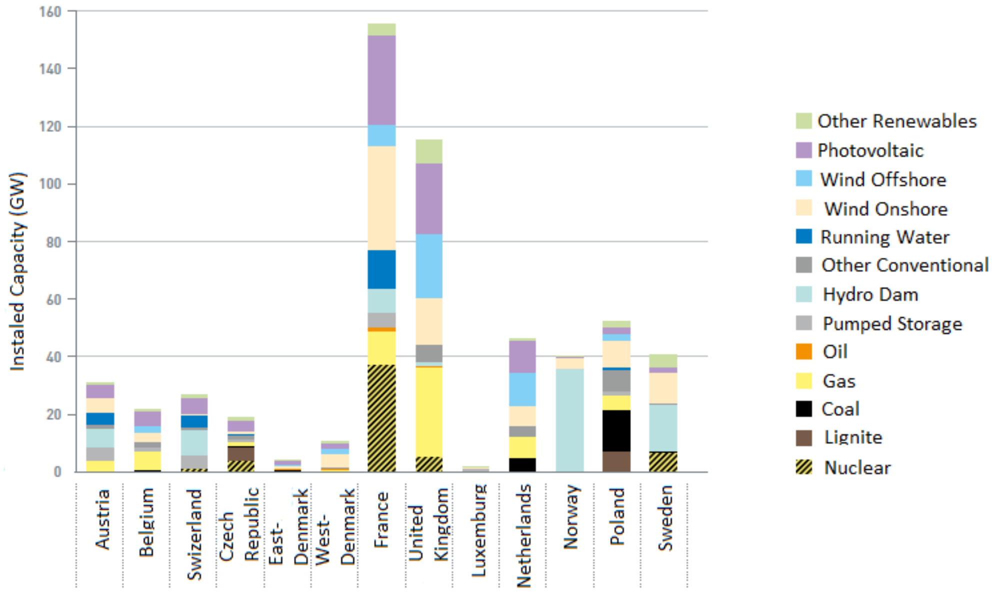
[165] The somewhat unilateral approach to changes in energy policy and the ongoing implications for neighbouring countries, which have to deal with German energy policy consequences, e.g., the closing of plants in view of low export prices, but also imports swinging to the tune of German wind capacity, may dampen enthusiasm to help Germany in the future.

[166] E.g., France, due to its large share of electric heating, it is highly dependent on winter peak load.

[167] However, the situation in the Netherlands has changed dramatically since the time of the IEA review, with the decision to close all coal-fired power plants by 2030.

the EU's Large Combustion Plant Directive. This is well illustrated in Figure 16, produced in the context of adequacy discussions within ENTSO-E.[168]

Figure 16: Resulting Capacity in Neighbouring Countries in the Scenario Sustainable Transition 2030



Source: ÜNB; (Jan 2018) Scenarios for the power grid development plan (NEP)for 2030 (draft 2019 version), p. 109

The NEP concludes that the size of the power gap emphasises the need to continuously monitor reliability of supply and the necessity of cross-border analysis.[169] Such an analysis also should include the implications of modelling for gas infrastructure and supply in Germany and the EU.

Appendix 3: Challenges of de-carbonising natural gas / hydrocarbons

Pre-combustion decarbonisation could take place anywhere upstream of the combustion point. The carbon contained in CH_4 can be separated through a well-known reforming process[170] any place along the chain suitable for carbon capture, i.e., close to geological structures. Decarbonising CH_4 at the wellhead and reinjecting the CO_2 would, on balance, exchange CH_4 for CO_2 in the reservoir. Using the existing pipeline grid for hydrogen transportation should be possible with some modifications.[171] Placing the reforming process along the chain is an issue of optimising the disposal of CO_2 *vs.* the costs of

[168] Scenarios for the power grid development plan (NEP) for 2030 (draft of the 2019 version)p. 109.
[169] Bundesnetzagentur (jan. 2018): Grid development strategy 2030, 2019 version , p. 98:
"At the same time, the calculated magnitude of underfunding clearly highlights the importance of ongoing security of supply monitoring and the need for comprehensive and cross-border analysis."
[170] Just as at the first stage of ammonia production. The process uses CH_4 and 2 x H_2O, resulting in CO_2 and 4 x H_2. These can then be used directly or further transformed by a Fischer-Tropsch process into NH_3 (as a carrier of hydrogen in liquid or gaseous form). All this is a well-known and broadly applied technology. For methane, the ratio of 4 x H_2 molecules per 1 CO_2 molecule to be disposed of is much better than for other hydrocarbons, requiring the least volume to store CO_2 per H_2 produced.
[171] H_2 has different flow properties than methane, so compressors would have to be modified, and H_2 burns at higher temperatures than CH_4, with implications for the turbine process.

transforming pipelines for H_2 use; this could be done at the wellhead or downstream, e.g., by re-pressurising declining fields like Groningen.

The energy content of CH_4 is transformed into the energy contained in decarbonised H_2 at a ratio of between 2/3 and ¾; the rest of the energy produced during the reforming process has to be used locally. H_2 or NH_3 are then carbon-free (and therefore have higher value) and ready for further use in a H_2 or NH_3 infrastructure, using existing transportation and distribution.[172]

In fact, all remaining hydrocarbon reserves could be decarbonised through a reforming process. This would allow to prolong the use of the existing infrastructure, initially designed for hydrocarbons, and to maintain the gas grid and storage as a way to transport and store large volumes of energy. Such a system would be compatible with the use of H_2, from surplus renewable power. Based on the size of hydrocarbon reserves, which would otherwise be left in the ground, or resources left unexplored, the guesstimate is that GHG free hydro carbons can be used for several decades. Such a timespan would allow private investment into the necessary infrastructure changes to pay off and continue using present hydrocarbon-based infrastructure.

In Germany and worldwide, the problem of introducing hydrogen use is the so far limited demand, concentrated in the chemical industry. Scaling up demand for a future change to a hydrogen-based energy consumption would require a structural jump, which may not be triggered by the market alone. However, this is also true for creating an all-electric infrastructure, which is based so far on a substantial support of €20 bln a year for wind and PV and further costs for building a renewables-oriented power grid. A transition process is needed for an all-electric economy, as well as for developing a hydrogen sector.

Renewables are produced domestically in most cases. Unlike existing hydrocarbon reserves, decarbonised or not, renewables do not raise the issue of rent transfer between producing and consuming countries. Hydrocarbon resource-holding countries may consider the push for renewables wrapped up in a PA-driven decarbonisation approach as a threat to devalue their resources and to weaken their economic and political position. This could be avoided by de-carbonising natural gas at the wellhead.

[172] The decarbonised gas can be in the form of H_2 or NH_3, which offer different advantages and disadvantages. For H_2: the existing pipeline infrastructure could be used, also the town grids, which in earlier times handled town gas with about 60% of H_2. Gas-driven turbines, e.g., in compressors, probably could not be run on H_2, as the combustion temperature would be too high. NH_3 is the second most used chemical material, after sulfuric acid; its world production is about 150 mln t/a. NH_3 could be used in gaseous and liquid form, apparently also in combustion engines and turbines. Both processes offer alternatives to the electrification of road transport via fuel cells or by using NH_3 in combustion engines.

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Abbreviations and Acronyms

Abbreviation/ acronym	German	English/Latin
AGEB	Arbeitsgemeinschaft Energie Bilanzen	working group for energy statistics
bcm/a		billion cubic metres a year
BDEW	Bundesverband der Energie und Wasserwirtschaft	Federal Association of Energy and water industries
BDH	Bundesverbands der Deutschen Heizungsindustrie	Federal Association for Heating Systems
BMBF	Bundesmisterium für Bildung und Forschung	Federal Ministry of Education and Research
BMU	Bundesministerium für Umwelt	Federal Ministry for the Environment
BMUB	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BMWi	Bundesministerium für Wirtschaft (und Energie)	Federal Ministry of Economics (and Energy)
BNetzA	Bundesnetzagentur	Federal Network Agency
Ca		circa
CAGR		compound annual growth rate
CCGT		combined-cycle gas turbine
CDU	Christlich Demokratische Union	Christian Democratic Union
CH_4		methane
CHP		combined heat and power
CNG		compressed natural gas
CO_2		carbon dioxide
COP		Conference of the Parties (to the UNFCCC)
COP 21		21st Conference of the Parties, held in Paris from 30 November to 12 December 2015
CSU	Christlich Soziale Union	Christian Social Union

DENA	Deutsche Energie Agentur	German Energy Agency
DH		district heating
DSM		demand-side management
EE		energy efficiency
EEG	Erneuerbare Energien Gesetz	Renewable Energy Act
El		electric
ENEV	Energieeinsparverordnung	Energy Saving Decree
ENTSO-E		European Network of Transmission System Operators for Electricity
ENTSO-G		European Network of Transmission System Operators for Gas
EnWG	Enegie Wirtschaftsesetz	Energy Industry Act
ESG	Energieeffizienz Strategie Gebäude	Energy Efficiency Strategy Buildings
ETS		Emissions Trading System
EU		European Union
EUA		European Emissions Allowance
FDP	Freie Demokraten	Free Democratic Party
FNR	Fachagentur Nachwachsende Rohstoffe	Agency for Renewable Resources
GCV		Gross Calorific Value
GHG		greenhouse gas
Gt		gigaton
GW		gigawatt
GW/h		gigawatt per hour (capacity gradient)
GWh		gigawatt hour
H_2		hydrogen
HVDC		high-voltage direct current
IEA		International Energy Agency

IPCC		Intergovernmental Panel on Climate Change
IRENA		International Renewable Energy Agency
IWR	Internationales Wirtschaftsforum Regenerative Energien	Institute for Renewable Energy
KfW	Kreditanstalt für Wiederaufbau	Reconstruction Credit Institute – German government-owned development bank
KWKG	Kraft Wärme Kopplungs Gesetz	Combined Heat and Power Act
LNG		liquefied natural gas
LPG		liquefied petroleum gas
MW		megawatt
MWh		megawatt hour
n-1 criterion		rule according to which the elements remaining after the occurrence of a contingency are capable of accommodating the new operational situation without violating operational security limits
NEP	Netzentwicklungsplan	Grid Development Plan
NH_3		ammonia
PA		Paris Agreement
PJ		petajoule
PtG		power-to-gas
PV		photovoltaic
REN		renewables
SAIDI		system average interruption duration index
SPD	Sozialdemokratische Partei Deutschlands	Social Democratic Party of Germany
TSO		transmission system operator
TWh		terawatt hour
UK		United Kingdom

UNFCCC	United Nations Framework Convention on Climate Change
WEO	World Energy Outlook (annual IEA publication)
WWII	Second World War