Dissertation

The role of natural gas in energy transitions

Path dependencies, lock-in effects, and governance strategies in the case of Germany

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Abstract

In order to meet the Paris climate targets, all fossil fuels must be phased out. However, at least before the energy crisis, natural gas was still considered a possible bridge technology leading towards a renewable future. Due to the crisis, the natural gas phase-out has entered the political discussion. Yet the measures taken to overcome the crisis, such as the expansion of natural gas infrastructure for importing liquefied natural gas (LNG), could lead to a further stabilisation of natural gas use. There is a high risk that path dependencies are strengthened and result in lock-in effects. The dissertation at hand deals with these phenomena in combining qualitative and interdisciplinary research approaches. In three of the four analyses, Germany serves as the object of study due to its characteristics as an extreme case. Germany has the most extensive natural gas infrastructure in the EU and is its largest consumer of natural gas and coal.

This dissertation is rooted in the field of transition research. Its content is divided into two parts. In the first part, an integrated literature review shows that the global expansion of natural gas infrastructure poses a risk to the success of the energy transition. Subsequently, the planning process for LNG terminals in Germany is analysed on the basis of a meta-theoretical framework. This analysis shows which lock-in mechanisms have led to political support for the terminals. The analysis focuses on the role of actors in the activation of lock-in mechanisms. Institutional, infrastructural, behavioural, and discursive lock-in types are considered. The first part of the dissertation concludes that for a timely natural gas phase-out to succeed, path dependencies and possible lock-in effects of natural gas must be identified and addressed with suitable political strategies.

The second part of the thesis then focuses on two selected political strategies. First, the instrument of municipal heat planning is examined for its possible contribution to overcoming path dependencies caused by the existing natural gas distribution networks. The results show that the instrument can make a contribution but needs to be flanked by further political measures. Furthermore, the analysis clarifies that the so far insufficiently studied field of behaviour-induced lock-ins harbours a great risk of delaying the heat transition. Finally, the suitability of expert commissions for overcoming the resistance of established actors in energy transition is scrutinized. In doing so, the coal phase-out in Germany is used as the object of analysis, as it is already further advanced. The analysis concludes that the set-up of the Commission was not optimal to reap all the benefits of a collaborative governance regime. Nevertheless, the Commission facilitated to overcome a long-standing stalemate situation by providing a safe space to build up trust and understanding.

The most important insights gained for the political implementation of the natural gas phase-out are: 1) Natural gas is a climate-damaging energy source and not a bridge technology, as it carries a high risk for all types of lock-ins. 2) The natural gas phase-out must be planned at an early stage. In this context, it is important to replace the narrative of the bridge technology with a clear phase-out plan. 3) Possible new natural gas infrastructure projects must be compatible with climate protection goals and should not be evaluated purely from the perspective of supply security. 4) Stakeholders and their perceptions play an important role in the activation of lock-in mechanisms. Their early involvement in transition processes can accelerate them. 5) Behaviour-induced lock-in mechanisms must be addressed with appropriate

policy measures. 6) The natural gas phase-out is closely linked to the heat transition. For the latter to succeed, appropriate expertise is needed in the municipalities and districts.

Keywords: Natural gas, liquefied natural gas (LNG), carbon lock-in, path dependencies, energy transitions, energy infrastructure, communal heat planning, expert commission, collaborative governance, climate change, heat transition

Zusammenfassung

Um die Pariser Klimaziele einzuhalten, muss die Nutzung aller fossiler Energieträger beendet werden. Zumindest vor der Energiekrise galt Erdgas jedoch als Brückentechnologie, die in eine erneuerbare Zukunft führen sollte. Aufgrund der Krise hat der Erdgasausstieg in die politische Diskussion Einzug gehalten. Allerdings können die ergriffenen Maßnahmen zur Krisenbewältigung, wie der Ausbau von Erdgainfrastruktur zum Import von Flüssiggas (LNG), zu einer weiteren Verstetigung der Erdgasnutzung führen, da Pfadabhängigkeiten verstärkt werden und daraus resultierende Lock-in-Effekte greifen. Die vorliegende Dissertation beschäftigt sich mit diesen Phänomenen in einer Kombination aus qualitativen und interdisziplinären Forschungsansätzen. In drei von vier Analysen wurde Deutschland als Untersuchungsgegenstand ausgewählt, da es ein Extremfall ist: Deutschland verfügt über die umfangreichste Erdgasinfrastruktur der EU und ist deren größter Erdgas- und Kohleverbraucher.

Diese Dissertation ist im Bereich der Transformationsforschung angesiedelt und inhaltlich zweigeteilt. Im ersten Teil wird anhand einer integrierten Literaturrecherche herausgearbeitet, dass der globale Ausbau der Erdgasinfrastruktur ein Risiko für das Gelingen der Energiewende darstellt. Des Weiteren wird anhand eines meta-theoretischen Frameworks der Planungsprozess von LNG-Terminals in Deutschland analysiert und aufgezeigt, welche Lock-in-Mechanismen zu einer politischen Unterstützung der Terminals geführt haben. In der Analyse wird insbesondere auf die Rolle von Akteuren beim Greifen von Lock-in-Mechanismen eingegangen. Dabei werden sowohl institutionelle, infrastrukturelle, verhaltensinduzierte als auch diskursive Lock-in-Typen berücksichtigt. Die Erkenntnisse aus dem ersten Teil der Arbeit zeigen auf, dass für einen zeitnahen Erdgasausstieg Pfadabhängigkeiten und mögliche Lock-in-Effekte von Erdgas identifiziert und mit passenden politischen Strategien adressiert werden müssen.

Der zweite Teil der Arbeit befasst sich mit zwei ausgewählten politischen Strategien. Zunächst wird das Instrument der Kommunalen Wärmeplanung auf dessen möglichen Beitrag zur Überwindung von Pfadabhängigkeiten, die durch das bestehende Erdgasverteilnetz verursacht werden, untersucht. Die Ergebnisse zeigen, dass das Instrument zwar einen Beitrag leisten kann, aber von weiteren politischen Maßnahmen flankiert werden muss. Weiterhin wird durch die Analyse deutlich, dass das bisher wenig erforschte Feld der verhaltensinduzierten Lock-ins ein großes Risiko für eine Verzögerung der Wärmewende birgt. Daran anschließend wird analysiert, ob das Instrument der Expertenkommission dazu geeignet ist, den Widerstand von etablierten Akteuren in Energietransformationen zu überwinden. Dabei wird auf den Kohleausstieg in Deutschland als Analysegegenstand zurückgegriffen, da dieser bereits weiter fortgeschritten ist. Die Analyse schlussfolgert, dass die Organisation nicht optimal war, um alle Vorteile einer solchen Expertenkommission entfalten zu können. Dennoch konnte die Kommission dazu beitragen, eine seit langem bestehende Pattsituation zu überwinden, indem sie einen sicheren Raum für den Aufbau von Vertrauen und Verständnis zwischen den beteiligten Akteuren geschaffen hat.

Aus der Analyse folgen einige zentrale Erkenntnisse für die politische Umsetzung des Erdgasausstieges: 1) Erdgas ist ein klimaschädlicher Energieträger und keine Brückentechnologie, da es ein hohes Risiko für alle Typen von Lock-ins birgt. 2) Der Erdgasausstieg muss frühzeitig geplant werden. Dabei ist es wichtig, das Narrativ der Brückentechnologie durch klare Ausstiegskriterien zu ersetzen. 3) Mögliche neue Erdgasinfrastrukturprojekte müssen mit den Klimaschutzzielen kompatibel sein und dürfen nicht nur aus der Perspektive der Versorgungssicherheit bewertet werden. 4) Akteure und ihre Wahrnehmung spielen eine wichtige Rolle beim Greifen von Lock-in-Mechanismen. Deren frühzeitige Einbindung in Transformationsprozesse kann diese beschleunigen. 5) Verhaltensinduzierten Lock-in-Effekten muss mit entsprechenden politischen Maßnahmen begegnet werden. 6) Der Erdgasausstieg ist eng verbunden mit der Wärmewende. Damit diese gelingen kann, braucht es entsprechende Expertise in den Kommunen und Landkreisen.

Schlüsselwörter: Erdgas, Flüssigerdgas (LNG), Lock-in, Pfadabhängigkeiten, Energiewende, Transformationsforschung, Energieinfrastruktur, kommunale Wärmeplanung, Expertenkommission, Kohlekommission, Klimawandel, Wärmewende

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Directories

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1 Introduction

1.1 Motivation

Throughout the 19th century, more and more European cities became illuminated at night due to the installation of gas lamps. This was celebrated by many as a welcome improvement of urban life. At first, the so-called town gas was used, which was produced by coking coal (Bouzarovski, Bradshaw, and Wochnik 2015). Following the discovery and development of the Groningen gas field in the Netherlands in the 1960s, natural gas became a relevant energy source in Europe beyond its use in lighting, and the expansion of gas infrastructure and usage accelerated. In the 1960s and 1970s, natural gas-fired heating became an ordinary part of everyday life for more and more households. During this time, expectations of living comfort increased, resulting in rising heat demand. Natural gas offered a comfortable substitute for coal and oil, as it causes neither dirt nor odors, can be installed in all rooms and controlled via a regulator (Hanmer and Abram 2017).

In the period from 1970 to 1980, European natural gas production doubled to almost 200 billion cubic meters (bcm) (Bouzarovski, Bradshaw, and Wochnik 2015) (see Figure 1). However, Europe's thirst for natural gas grew so rapidly that its own production capacities could no longer meet the demand. This led to the expansion of the European pipeline network, enabling the international trade of natural gas. The expansion was additionally driven by the oil crisis. The first major import routes allowed Western European countries to import natural gas from Algeria and Norway as well as from Russia via Eastern Europe (IEA 2008). Long-term supply contracts secured the high investment costs in infrastructure.

At the end of the 1990s, natural gas became the second most widely used energy source in the EU, while domestic production decreased. In the period from 2010-2020, primary energy production fell for all fossil fuels, although the production of natural gas experienced the steepest decline (-62.4 %). The quantity of imported natural gas more than doubled from 1990 to 2020, making natural gas the most imported energy product after oil.[1] By now, EU countries have installed over 260,000 km of high-pressure transmission pipelines and LNG terminals with a capacity of 157 bcm[2], enabling the import of natural gas as well as transport over long distances (Terlouw et al. 2019). Roughly 40% of EU households are connected to a natural gas distribution network with a combined length of 1.4 million kilometers.[3] Natural gas is now used in almost all sectors, although primarily in the provision of low-temperature heat. 40% of building heat and hot water is provided by natural gas (European Commission. Directorate General for Energy et al. 2022) (see Figure 1). In 2020, the share of natural gas in primary energy consumption in the EU was 24 % whilst renewable energy (including hydropower) accounted only for 18 % (see Figure 1).

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[1] Eurostat. 2023. “Energy Statistics – an overview.” Accessed February 18, 2023. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview

[2] European Council and Council of the European Union. 2022. “Infographic - Liquefied natural gas infrastructure in the EU.” Accessed February 18, 2023. https://www.consilium.europa.eu/en/infographics/lng-infrastructure-in-the-eu/#:~:text=The%20EU's%20overall%20LNG%20import,is%20uneven%20across%20the%20EU.

[3] ACER. 2022. “Gas Factsheet.” 2022. Accessed February 18, 2023. https://www.acer.europa.eu/gas-factsheet.

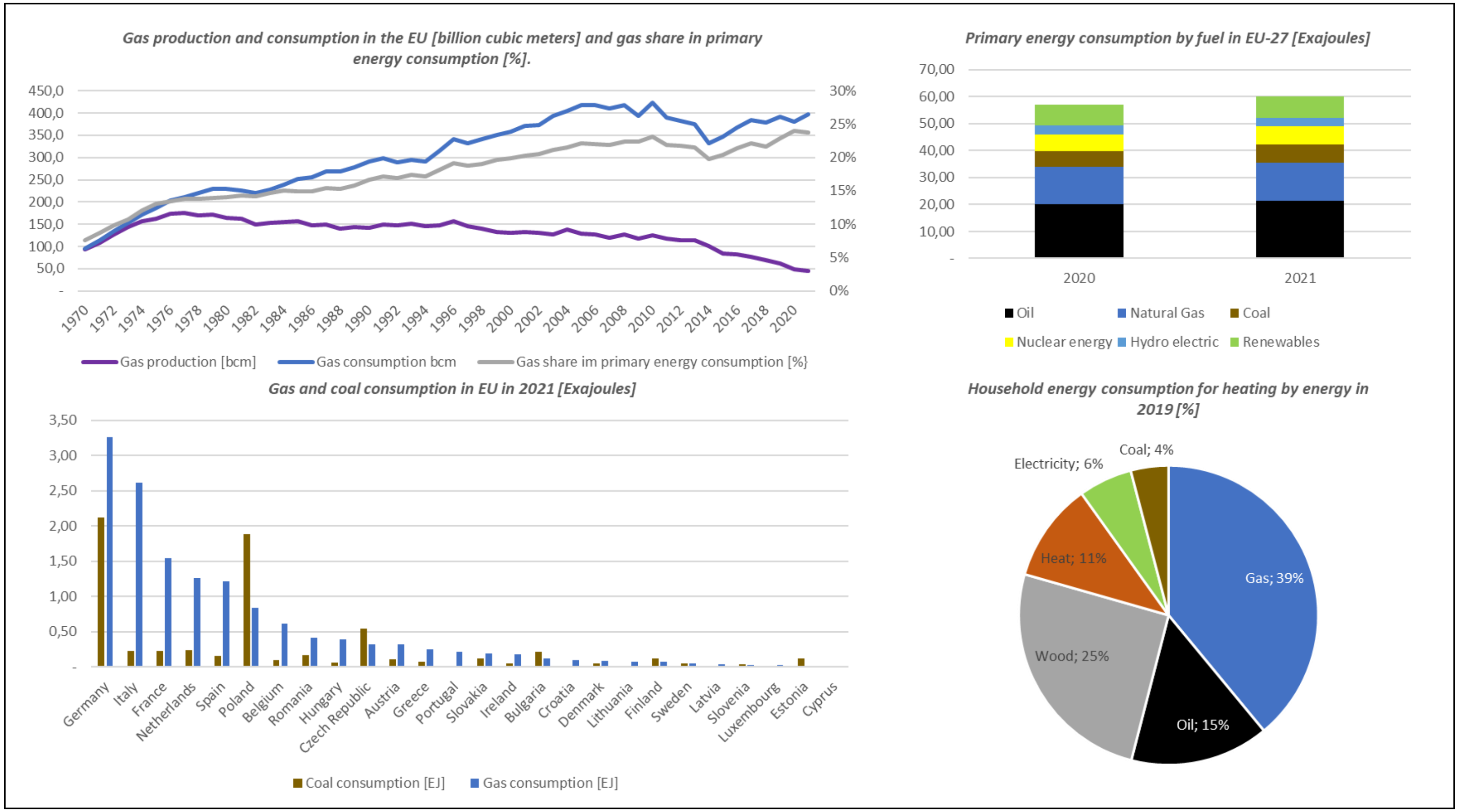

Figure 1: Overview of natural gas in the EU and Germany as an extreme case.

Source: (BP 2022).[4]

[4] Household energy consumption is based on: Odysee-mure. 2021. Accessed February 22, 2023. https://www.odyssee-mure.eu/publications/efficiency-by-sector/households/heating-energy-consumption-by-energy-sources.html.

The natural gas infrastructure is a natural monopoly. To protect consumers from excessively high prices and to ensure security of supply, its expansion is regulated by the European regulatory authority Agency for the Cooperation of Energy Regulators (ACER). The member states are responsible for regulation on a national level (EY 2013). In addition, the European Network of Transmission System Operators for Gas (ENTSOG), an umbrella organization for the transmission system operators of the Member States, was established in 2009. Every two years, ENTSOG develops a Ten Year Network Development Plan (TYNDP) based on its own forecasts of future gas consumption in the EU. It then selects natural gas infrastructure projects that have applied as Projects of Common Interest (OJ 2013). The selected projects benefit from fast approval procedures and qualify for various funding possibilities (EC 2017). However, scenario development by ENTSOG is not transparent and demand development is regularly overestimated (Prognos AG and Ecologic Institute 2018). Furthermore, the monitoring of the TYNDP by ACER is not designed to identify whether the network development plan is in line with political priorities of the EU, such as climate protection targets. The EU reference scenario, which is regularly published by the EU Commission and serves as a "benchmark for new policy initiatives" (European Commission 2020, 8), also systematically overestimates future gas consumption (Neumann et al. 2018). The existing institutional setting at EU level thus favors the development of natural gas infrastructure in Europe. Therefore, while several Member States have already decided to phase out coal, it is not surprising that the use of natural gas in primary energy consumption has increased since the 1990s (see Figure 1).[5]

In the remaining part of this introduction, the focus of this dissertation on natural gas is further explained and the case of Germany is presented. An excursus places the work in the context of the current energy crisis. Subsequently, the dissertation is embedded in the field of sustainability transition research and relevant theoretical concepts for the analysis are introduced. The methodological approaches applied in the individual chapters are summarized in the methodology section. This is followed by an overview of the different parts of the dissertation and the author's contribution to it. The introduction concludes with an outline of the key findings and shortcomings and finally provides a research outlook.

1.1.1 Climate impact of natural gas

The substitution of coal with natural gas was and is still often advocated with the argument that the combustion of natural gas produces less CO_2 and other air pollutants (see e.g. Yang, Hastings-Simon, and Ravikumar 2022; Ladage et al. 2021). However, the climate benefits of a coal-to-gas switch are questionable since natural gas consists largely of methane. Methane is a very potent greenhouse gas (GHG) that leaks into the atmosphere during the production and transport of natural gas. This has been pointed out by academics as early as the 1990s (D. Wilson 1990; Tie and Mroz 1993).

The GHG emissions advantage of natural gas over coal becomes marginal if approximately 3.2% (Alvarez et al. 2012) to 3.4% (Schwietzke et al. 2014) of the gas produced escapes into the atmosphere before its end use. There is still a lack of robust data on how much methane emissions occur in the EU, as for a long time the GHG inventories relied only on estimated values or standard emission factors.

[5] Europe Beyond Coal. 2022. “Europe’s Coal Exit Overview of national coal phase out commitments.” Accessed February 18, 2023. https://beyond-coal.eu/europes-coal-exit/; Eurostat. 2023. “Energy Statistics – an overview.“ Accessed February 18, 2023. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Energy_statistics_-_an_overview.

Measurements in the US and Canada have found that actual methane leakage rates far exceed previous estimates (Schwietzke et al. 2016; MacKay et al. 2021). The EU Commission responded to this findings with its 2020 methane strategy in 2020 (EC 2020b). Proposed measures include measuring methane emissions, setting mandatory requirements for leak detection and repair methods, and restrictions on natural gas venting and flaring (Olczak, Piebalgs, and Balcombe 2022). Yet specific regulations with clear reduction targets, analogous to those for CO_2, are still missing.

While the coal-to-gas switch may have been an acceptable strategy for reducing GHG emissions in the 1990s, this is no longer the case thirty years later. Renewable energies are available at low cost (IEA 2020c) and the methane concentration in the atmosphere is increasing (Nisbet et al. 2019). Under these conditions, it no longer appears sensible to build long-lived natural gas infrastructures.

1.1.2 Bridge technology narrative

Instead of a clear phase-out plan for natural gas with binding reduction targets, the narrative of gas as a bridge technology has become established in the political and public discourse. Narratives are “simple stories that describe a problem, lay out its consequences and suggest (simple) solutions” (Hermwille 2016, 238). In contrast to a concrete phase-out plan, the narrative remains vague at important points. For example, it remains unclear when the bridge is to be completed or where the bridge exactly leads to. Due to this ambiguity, many actors with very different interests can agree on the narrative.

In order to function, a narrative must have additional qualities, including that it must be coherent within itself, even if it is not fact-based (Hermwille 2016). For a long time, the potential CO_2 reductions from a coal-to-gas switch alone were enough to support the narrative of natural gas as a bridge technology and to justify the construction of new fossil infrastructure in the EU. This is no longer the case, as the operational lifetime of such large-scale infrastructure now conflicts with the EU's goal of becoming climate neutral by 2050. The argument that natural gas is needed as a flexible back-up to renewables is also losing its ground as an increasing body of research is backing the feasibility of 100% renewable energy systems (Hansen, Breyer, and Lund 2019). Other flexibility options, such as energy storage options, demand response, and sector coupling will at best replace the use of natural gas entirely or at least reduce it to a minimum in order to overcome technical difficulties (Williams et al. 2021). It is therefore already becoming apparent that the transition of the energy system will lead to very low shares of capacity utilization of natural gas infrastructure (McGlade et al. 2018) and that large parts of the infrastructure will therefore no longer be needed (Wachsmuth et al. 2019).

To restore coherence, some actors argue that natural gas can be decarbonized by blending or completely replacing it with hydrogen or synthetic methane. In this way, the gas infrastructure could still be used in a renewable energy system (Stern 2019). Regardless of whether a repurposing of the infrastructure is at all technically feasible or economically viable, a complete substitution of natural gas with renewable or synthetic gases is unlikely due to numerous restrictions on the production of these gases and the existence of more efficient alternatives (Shell 2018; IEA 2020c; EC 2020c; Matthes et al. 2018). For instance, due to conversion losses, the production of renewable hydrogen depends on an even faster and more extensive expansion of renewable energy capacities than it would be the case of direct electrification (Braunger, Grüter, and Präger 2021). The use of hydrogen from steam methane reformation emits more GHG than the use of natural gas itself (Bauer et al. 2021; Howarth and Jacobson

2021). In the case of synthetic methane, which is most compatible with the existing natural gas infrastructure, the problem of methane leaks remains, with the added problem of very poor efficiency rates (Agora Verkehrswende, Agora Energiewende, and Frontier Economics 2018).

1.1.3 Risk of natural gas lock-in

The use of natural gas has been established in the EU for many decades and path dependencies exist through an extensive infrastructure, well-connected and influential actors with a high interest in continuing to operate it, and strong institutions ensuring its maintenance and expansion. Furthermore, consumers, suppliers, and installers of heating systems have adapted their behavior and professional expertise to its use since the 1960s. Under the banner of bridge technology and security of supply, natural gas infrastructure continues to be expanded. There is a risk that the existing infrastructural, institutional, behavioral, and discursive path dependencies will lead to carbon and methane lock-in mechanisms (see section 1.2.3), slowing down the transition and possibly preventing the achievement of climate goals.

The planning and governance of a climate-neutral energy system is a major challenge and the (timely) transition can only succeed if existing path dependencies are identified and addressed to avoid carbon and methane lock-ins. In this context, lessons learned from already advanced phase-out processes, such as coal, can provide helpful insights. This dissertation aims to contribute to identifying path dependencies and lock-in effects hindering the natural gas phase-out, using Germany as a case study. Germany represents an extreme case within the EU and is therefore particularly informative as a research subject (see section 1.3.3). In addition, Germany, like other EU countries, is already in an advanced phase of the energy transition, in which the dynamics of regime resistance by incumbent actors make it difficult to overcome path dependencies and possible carbon and methane lock-in mechanisms take effect (see section 1.2.2). Research results can be relevant for other EU countries in a similar phase of their energy transition and inform the policy process there. A natural gas phase-out in the EU's largest economy could serve as a blueprint for other countries.

1.1.4 Germany as a(n extreme) case

Germany is the largest consumer of natural gas and coal in the EU (see Figure 1) and both energy sources are strongly anchored in the economy and at the political level through influential and well-connected actors (von Hirschhausen et al. 2018; Fitzgerald, Braunger, and Brauers 2019).

Germany is the largest natural gas consumer (2021: 104 bcm) in the EU, followed by Italy (2021: 82 bcm) and France (2021: 49 bcm).[6] Germany has an extensive natural gas infrastructure including the largest natural gas pipeline network in the EU (33,500 km of transmission pipelines and 522,000 km of distribution networks) with 13 million connected households, cross-border connections to all its neighbors, to Russia, and to Norway, as well as the largest gas storage capacities (~23 bcm) in the EU (the fourth largest in the world) (BNetzA and BKartA 2021).[7] Due to its central location in the EU and

[6] Eurostat. 2023. “Supply, transformation and consumption of gas.“ Accessed February 18, 2023. https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_gas/default/bar.

[7] INES. 2023. “Gas storage capacities.” Accessed February 18, 2023. https://erdgasspeicher.de/en/gas-storage/gas-storage-capacities/.

existing storage facilities, Germany has acted as a "gas hub" for Europe in the past. More than 50 percent (77 bcm) of the imported natural gas was transferred to neighboring countries in 2021 (BNetzA and BKartA 2022). Irrespective of the current management of the energy crisis (see section 1.1.5), new investments are continuously flowing into the expansion and maintenance of the infrastructure (FNB Gas 2021; BNetzA and BKartA 2021). In 2019, distribution system operators invested 1.5 billion euros in their networks (BNetzA and BKartA 2021, 364–65). Since the German coal phase-out law became effective in July 2020, the conversion from coal-fired power plants has been financially incentivized - not only to renewable energies but also to natural gas.[8] While the use of all fossil fuels in Germany has decreased since 1990, the share of natural gas has almost doubled since then,[9] causing more than a quarter of energy-related CO_2 emissions in 2020.[10]

With an annual consumption of 179,000 tons of coal, Germany is the largest coal consumer in the EU (see Figure 1).[11] Germany is also the EU's largest lignite producer, with a high regional economic dependence on coal in its mining regions (Jewell et al. 2019; Oei, Brauers, and Herpich 2020; EUROCOAL 2022). The country has already managed a large part of its coal phase-out (Oei, Brauers, and Herpich 2020; Stognief et al. 2019). Overall employment in the coal sector decreased from approximately 600,000 direct jobs in the 1950s to less than 20,000 in 2019 (DIW Berlin, Wuppertal Institut, and Ecologic Institut 2019). Nevertheless, the coal phase-out did not make it onto the political agenda for a long time and when it finally came up for discussion, influential advocates such as the coal industry and its associated trade unions, energy-intensive industries, as well as local politicians in the coal-mining regions managed to defeat several political attempts to reduce coal use in Germany (Furnaro 2022; Hermwille and Kiyar 2022; Kalt 2021; Leipprand and Flachsland 2018). One attempt to overcome existing carbon and methane lock-ins was to set up an expert commission in 2019. The agreement of the so-called "Coal Commission" received wide attention and was celebrated by many as a milestone to phase-out coal.

1.1.5 Excursus: Energy crisis of 2022

Since 2021, the energy economy and energy policy situation in the EU have changed significantly, especially with regard to natural gas. Natural gas prices already increased considerably in the third quarter of 2021.[12] This was due to the global increase in natural gas demand as a result of the economic recovery after the Covid-19 pandemic, declining natural gas production within the EU, and lower

[8] BMWi. 2020. "Gesetz zur Reduzierung und zur Beendigung der Kohleverstromung und zur Änderung weiterer Gesetze (Kohleausstiegsgesetz)." Accessed February 18, 2023. https://www.bmwi.de/Redaktion/DE/Artikel/Service/kohleausstiegsgesetz.html.

[9] Umweltbundesamt. 2022. "Energieverbrauch nach Energieträgern und Sektoren." Accessed February 18, 2023. https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren#entwicklung-des-endenergieverbrauchs-nach-sektoren-und-energietragern.

[10] Umweltbundesamt 2022. "Energiebedingte Emissionen." Accessed February 18, 2023. https://ec.europa.eu/eurostat/databrowser/view/NRG_CB_SFF/default/bar?lang=de&category=nrg.nrg_quant.nrg. _quanta.nrg_cb https://www.umweltbundesamt.de/daten/energie/energiebedingte-emissionen#energiebedingte-kohlendioxid-emissionen-durch-stromerzeugung.

[11] Umweltbundesamt. 2022. Op. cit.

[12] ICE. 2023. "Dutch TTF Natural Gas Futures." Accessed February 18, 2023. https://www.theice.com/products/27996665/Dutch-TTF-Natural-Gas-Futures/data?span=3&marketId=5477499.

volumes of natural gas deliveries from Russia (Luderer et al. 2022). Russia's invasion of Ukraine in February 2022 aggravated the situation, especially after Russia severely reduced (or, in some cases, completely stopped) gas deliveries to some EU Member States. From January to September 2022, around 50% less Russian pipeline gas was delivered to the EU compared to the same time period a year prior (BNetzA and BKartA 2022; IEA 2022a). In response, gas prices in the EU spiraled out of control, increasing more than tenfold in August compared to the previous year (EC 2022a).[13] The Nord Stream°1 and Nord Stream°2 pipelines (which had not been commissioned by then) were the target of an act of sabotage at the end of September 2022. The loss of imports from Russia could be partially replaced by increased natural gas supplies via pipeline from UK, Algeria, Azerbaijan and Norway, as well as by additional LNG imports (EC 2022a).

The energy crisis made it clear to many citizens and political decision-makers how dependent the EU is on natural gas imports, especially from Russia, and consequently the EU recognized its vulnerability to geopolitical developments. The high dependence on natural gas imports is likely to intensify in the future. In the first half of 2022, natural gas production was significantly below the production level of previous years (EC 2022a), despite limited import volumes. The largest natural gas producer in the EU, the Netherlands, will close its Groningen field by 2024 at the latest (EC 2022a).

It is not yet possible to assess the extent to which the energy crisis will lead the EU or individual Member States to draw up concrete plans for phasing out natural gas or to implement policies that reinforce existing path dependencies. This is shown, for example, by the Repower EU Plan, which the EU adopted in May 2022 to reduce dependence of Russian natural gas imports and to improve security of supply.[14] While some measures to reduce import dependency on fossil fuels have synergies with climate protection efforts, such as the rapid implementation of solar and wind energy projects or the (voluntary) reduction of gas consumption by 15% compared to the average consumption of the last five years,[15] other measures can reinforce path dependency and lead to carbon and methane lock-in effects. These include the search for alternative sources of natural gas, for which new import and export infrastructure has to be developed. For example, in addition to the existing 157 bcm, a further 150 bcm of LNG import capacities are planned in the EU by 2026, around 70 bcm of which in Germany alone (BMJ 2022).[16]

To accelerate the implementation of the projects, Germany passed the LNG Acceleration Act (LNGG), which allows for exemptions from environmental impact assessment (BMJ 2022). To ensure a timely import of LNG and to keep carbon and methane lock-in effects of the terminals low, floating storage and regasification units (FSRUs) (approx. 20 bcm in Germany) are partly used instead of building onshore

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[13] ICE. 2023. Op. cit.

[14] EC. 2022. "REPowerEU: affordable, secure and sustainable energy for Europe." Accessed February 18, 2023. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en.

[15] European Council and Council of the European Union. 2022. "Council adopts regulation on reducing gas demand by 15% this winter." Accessed February 18, 2023. https://www.consilium.europa.eu/en/press/press-releases/2022/08/05/council-adopts-regulation-on-reducing-gas-demand-by-15-this-winter/.

[16] See also BMWK. 2022. "FAQ-Liste LNG-Terminal in Deutschland." Accessed December 12, 2022. https://www.bmwk.de/Redaktion/DE/Downloads/F/faq-liste-lng-terminal-in-deutschland.pdf?__blob=publicationFile&v=8. GIE. 2022. "LNG Import Terminals Map Database." Accessed December 12, 2022. https://www.gie.eu/transparency/databases/lng-database/.

terminals. However, the use of FSRUs can still lead to carbon and methane lock-ins. For example, at all the locations mentioned in the LNGG, an extension of the pipeline network is necessary to feed the imported natural gas into the grid. Furthermore, the additional German (and European) demand for LNG cannot be met by the existing supply on the LNG market. An additional expansion of export infrastructure as well as the development of new or the expansion of existing natural gas fields is the consequence, regardless of whether the natural gas is then imported via an FSRU or an onshore terminal (IGU 2022).

In the case of land-based terminals, the federal government argues that the carbon and methane lock-in risk will be minimized by ensuring that they can be used for, or at least be converted to, importing renewable gases (BMJ 2022).[17] The production and use of renewable gases are still at an early stage of development and it is difficult to foresee in which form and from which regions they will be imported to Europe (Braunger, Grüter, and Präger 2021). However, in order to enable conversion at a later date, these factors would already have to be taken into account during the planning and construction stages (Riemer, Schreiner, and Wachsmuth 2022).

The extent to which the planned LNG import capacities of 70 bcm are actually necessary to ensure security of supply is controversial (Höhne, Marquardt, and Fekete 2022). Until the end of 2022, Germany did not have its own LNG import terminal, but imported gas mainly via terminals in Belgium and the Netherlands and the existing pipeline infrastructure (BNetzA and BKartA 2022). By using capacities of neighboring countries, it was possible to fill German natural gas storage facilities, which had been at a historically low storage level at the end of the 2021/2022 heating period, to 95% by mid-October 2022.[18] This was possible, among other factors, because a large reduction in consumption or substitution of natural gas was achieved in all sectors (Ruhnau et al. 2022). Nevertheless, it became apparent that the bottleneck was not the lack of import capacities, but the lack of available quantities on the LNG market.

Measures to increase efficiency and substitute fossil energy sources have received little political attention so far but must be increasingly implemented in the coming year to minimize the existing undersupply on the global natural gas market (IEA 2022b). In contrast to fossil infrastructures, these measures are necessary in the short, medium, and long term to achieve climate protection goals and reduce the dependence of Germany and the EU on fossil energy imports.

The current developments on the gas market cannot be considered in this dissertation, as data collection for all publications was completed before the emergence of the energy crisis in 2022. However, the examples of the Repower EU Plan and the LNG terminals in Germany show that the energy crisis has increased the complexity of the relationship between climate protection, energy transition, and supply security and has triggered dynamics that reinforce path dependencies and can result in lock-ins of natural gas which hinder a sustainable transition. The results of this study contribute to a better understanding of how these phenomena work and will therefore continue to be relevant.

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[17] See also BMWK. 2022. Op. cit.

[18] Bundesnetzagentur. 2023. “Aktuelle Lage Gasversorgung.” Accessed February 18, 2023. https://www.bundesnetzagentur.de/DE/Gasversorgung/aktuelle_gasversorgung/_svg/Gasspeicher_Fuellstand/Speicherfuellstand.html?nn=1077982.

1.1.6 Research aim and objectives

1.1.6.1 Research aim

The energy crisis has drawn attention to natural gas, which, until recently, has been less in the focus of research on carbon lock-ins and path dependencies (especially in the low-temperature heat sector) than, for example, coal (Fisch-Romito et al. 2021). The fact that lock-in research has not yet focused as strongly on natural gas is also evidenced by the term "carbon lock-in", which does not include the GHG methane. In the introduction to this thesis, the term "carbon and methane lock-in" is used instead to explicitly include this very potent GHG.

Due to manifold path dependencies, the phase-out of natural gas will be a major challenge and requires planning and governance strategies. The aim of this dissertation is therefore to generate (context-specific) knowledge on the risks of carbon and methane lock-ins, study the dynamics between incumbent actors and carbon and methane lock-in mechanisms, as well as to derive strategies to overcome existing path dependencies and prevent lock-ins of natural gas. Moreover, the dissertation contributes to the further development of theoretical conceptualizations of path dependencies and lock-ins. In doing so, the dissertation will supplement the social science knowledge base for a natural gas phase-out, for example in enabling comparative studies and providing sustainability transition research scholars with a concept to analyze four types of path dependencies. The dissertation will also inform political actors in countries that, like Germany, are already in a more advanced phase of the energy transition and enable them to further develop appropriate political strategies (Flyvbjerg 2006).

1.1.6.2 Research objectives

The research aim of this dissertation is translated into four specific research objectives (RQ1 – RQ4), each of which is addressed in one chapter. The thesis is divided into two parts, each consisting of two chapters (see Figure 2). Three of the four chapters use Germany as a case study. Part 1 (chapters 2 and 3) is dedicated to a better understanding of path dependencies from natural gas infrastructure, associated institutions, behaviors, and narratives as well as the possible resulting risks of carbon and methane lock-ins. Furthermore, the role of actors in the activation of carbon and methane lock-in mechanisms is examined. Part 2 (chapters 4 and 5) analyses two governance strategies (communal heat planning and expert commissions) with respect to their potential to help overcome path dependencies and prevent carbon and methane lock-ins and analyses their suitability for overcoming regime resistance. For the latter, the process of coal phase-out is taken into account, insights from which can be applied to other transitions like the natural gas phase-out.

Part 1 – Path dependencies from natural gas and the resulting risk of lock-ins

Chapter 2: The expansion of natural gas infrastructure puts energy transitions at risk

Chapter 2 identifies five widespread assumptions about the future role of natural gas and challenges them from a climate science, economics, and political science perspective in order to answer RQ1 of this dissertation:

Do current global developments in natural gas infrastructure expansion create a risk for sustainable energy transitions?

Chapter 3: Liquefied natural gas expansion plans in Germany: The risk of gas lock-in under energy transitions

In chapter 3, the planning process of LNG terminal construction in Germany is analyzed. The analysis takes developments in the techno-economic, political, and socio-technical system into account to address RQ2:

How do the material conditions around natural gas consumption and LNG infrastructure relate to and interact with actors' perceptions of these conditions? How do these interactions shape systemic changes and create lock-ins for the German energy transition?

Part 2: Governance strategies for overcoming path dependencies and preventing carbon and methane lock-ins

Chapter 4: Communal heat planning: Overcoming the path dependency of natural gas?

Chapter 4 assesses whether the instrument of municipal heat planning is suitable for overcoming path dependencies caused by the natural gas distribution infrastructure and answers RQ3:

Is municipal heat planning, as stipulated in the Climate Protection Act of Baden-Württemberg, a suitable instrument to overcome path dependencies through existing natural gas distribution networks and to implement a partial decommissioning of the networks?

Chapter 5: Overcoming political stalemates: The German stakeholder commission on phasing out coal

In Chapter 5, it is examined whether the instrument of the expert commission is suitable for overcoming the resistance of regime actors in energy transitions. This chapter answers RQ4:

How can a political process be designed and managed to achieve a coal phase-out in the event of incumbent actors blocking coal phase-out policies?

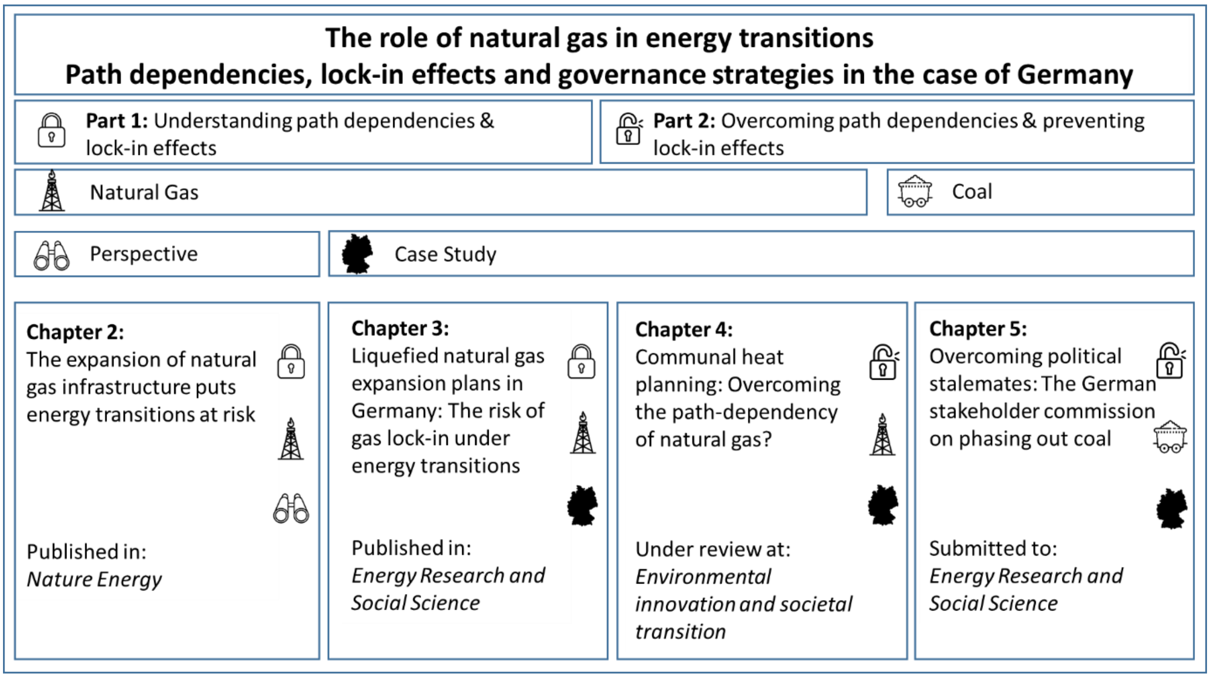

Figure 2: Outline of the dissertation.

1.2 Sustainability transitions research

This dissertation is rooted in the field of sustainability transitions research. Sustainability transitions are socio-technical transitions that are associated with sustainability targets, guided by public policies, and can be viewed as a response to the grand sustainability challenges such as climate change. They make the normative assumption that certain sectors (e.g., the energy sector) are unsustainable and have to change to achieve certain goals (such as those in the Paris Agreement). This means that sustainability transitions are value-based and therefore contested among actors (Markard, Raven, and Truffer 2012). Socio-technical transitions are fundamental, multi-dimensional (e.g., technological, institutional, sociocultural), and long-term changes of socio-technical systems (F. W. Geels 2002; A. Smith, Voß, and Grin 2010). In other words: technological transitions are analyzed in their social and political context, which is why interdisciplinary approaches are of particular importance in this field of research.

1.2.1 Central concepts: niche and regime

Central concepts in sustainability transition research are the socio-technical regime and the socio-technical niche. The concept of the regime comprises established rules, institutions, technologies, and infrastructures, but also user practices, science, or cultural meaning. Regimes impose the direction of development along established pathways and are temporally and structurally persistent (Markard, Raven, and Truffer 2012). Niches, on the other hand, are protected spaces in which new technologies can develop. Once these technologies have reached a certain stage of development, they can replace existing technologies under certain circumstances (Kemp, Schot, and Hoogma 1998; F. Geels and Raven 2006).

Various branches of sustainability transition research are based on these two concepts. Strategic niche management (SNM) is dedicated to researching the deliberate creation and support of niches to facilitate regime shifts (Kemp, Schot, and Hoogma 1998; Hoogma 2002). Technological innovation systems (TIS) research is concerned with the emergence of novel technologies and the institutional and organizational changes that have to go hand in hand with technology development (B. Carlsson and Stankiewicz 1991; Jacobsson and Johnson 2000). Based on an analysis of long-term historical transitions across a wide range of empirical domains, the Multi-Level Perspective (MLP) was developed. It explains technological transitions through the interplay of dynamics at three different levels: niches, regimes, and landscape. The landscape forms an exogenous environment for the niche and regime and is beyond the direct influence of actors (F. W. Geels and Schot 2007; A. Smith, Voß, and Grin 2010; F. W. Geels 2002; Rip and Kemp 1998).[19]

The initial focus of sustainability transition research on the socio-technical niche was driven by the assumption that the nurturing of niche innovations would lead to the displacement of regimes (F. W. Geels et al. 2017). York and Bell (2019) show that the expansion of renewable energies in the energy sector does not automatically lead to a decline in fossil fuels. Instead, past energy transitions across the world have largely been energy additions. A new energy source (e.g., oil) has not replaced a previous one (e.g., coal), but merely served to meet increased demand; this is also observed in the case of renewable energies. This does not imply that fossil fuels have not been replaced by renewables in electricity generation at the national level, as it is the case in Germany. However, the development of renewable energies was contested and met with regime resistance. A new stage in the transition process was reached.

1.2.2 Advanced energy transitions

Sustainability transitions undergo different phases, from the emergence of new technologies and actors and the development of new institutions to the achievement of technological maturation and the decline of established technologies and the resulting regime resistance. While transition processes in the first phase, such as the emergence of niche technologies, are already well researched, a better understanding is still needed for the second phase. This phase is not just a linear continuation of the first phase, but a qualitatively different process. The second phase begins when the growth of new technologies has accelerated to an extent where the established regime is challenged. The diffusion of new technologies causes a decline in the use of fossil energy sources and established technologies, which leads to increased resistance from regime actors. In addition, unidentified and unaddressed carbon and methane lock-in effects can slow down the transition (Markard 2018). Research on this phase is no longer concerned with understanding the emergence of new technologies, but with understanding the inertia of a system and barriers for transitions. In the second phase, the complexity of the transition processes increases. For example, it is no longer sufficient to focus on individual technologies; instead, new approaches are needed to understand and explain complex dynamics (Köhler u. a. 2019).

[19] Another important strand of transition research is transition management, a practice-oriented approach to accompany and steer transformations (Kemp and Loorbach 2006; Loorbach 2010).

1.2.3 Path dependency, carbon and methane lock-in

The concepts of path dependency and carbon lock-in are applied in various research disciplines (Goldstein et al. 2023). However, past research has largely focused on techno-economic and institutional path dependencies. This dissertation contributes to the theoretical framework of path dependencies by taking an interdisciplinary approach that considers and brings together the different perspectives of economics, political science, sociology, and discourse analysis. For this purpose, I conceptualize four types of path dependency based on the existing literature in the respective disciplines and apply them in my analysis.

From a techno-economical perspective, path dependency can be defined as increasing returns to the adoption of a specific technology (positive feedback) which gives incumbent technologies advantages over niche technologies, not necessarily because of their technological superiority but because they are more widely used (David 1985). Four major intertwined and mutually reinforcing types of increasing return were identified in the literature: scale economies, learning effects, network economies, and adaptive expectations (Arthur 1994; Unruh 2000). Scale economies arise when production costs per output decrease as production quantity increases and fixed costs can be distributed over a larger number of outputs. Learning effects arise when specialized skills and knowledge accumulate through production and market experience. Technical and organizational improvements can be identified and implemented, reducing production and supply costs over time. Network economies result from the coordination of different actors in a system and the development of common standards or regulations. The more widespread a technology becomes, the more confident consumers, manufacturers, and service providers become in dealing with associated quality standards and their trust in the permanence of the technology grows (adaptive expectations); hence, the advantage of using the technology increases (Arthur 1994; Unruh 2000; Klitkou et al. 2015; Janipour et al. 2020).

Modern technological systems are deeply embedded in institutional structures, both formal and informal. This interrelatedness further reinforces path dependencies (Unruh 2000). Institutions are developed with the intention to reinforce the technological system due to a general interest in having functioning and reliable technological systems, for example, to serve a growing demand for cheap energy rather than small-scale, mutually competing and ever-changing technologies (Gross and Hanna 2019). In addition, institutional developments are themselves subject to path dependencies and cannot be changed without resistance (North 1990; Pierson 2000).

Consumption patterns, user practices, social norms and lifestyles also follow path dependencies (Maréchal 2009; Kallis and Norgaard 2010; Büttner and Grübler 1995; Maréchal 2010). Behavioral factors of path dependency have so far been insufficiently addressed in research, although these are path dependencies that sometimes persist over much longer periods than path dependencies of institutional or technical origin (Seto et al. 2016).

Buschmann and Oels (2019) identify discursive path dependencies by drawing on the literature on discourse analysis, which assumes that language is not a neutral medium capable of describing an objective reality but is loaded with norms and values. Based on these values, actors contribute their perspectives, for example in the form of narratives. From these perspectives, discourses emerge that shape social action (Hajer 1997). The creation of a widely valid social understanding, i.e., a hegemonic narrative in a discourse, initially requires high investment costs. To become hegemonic, the narrative must be frequently shared with other social actors, creating learning effects and adaptive expectations (Pierson 2000).

Lock-ins are conceptualized as mechanisms that lead to or reinforce path dependencies. Lock-in mechanisms take effect when a new path should be taken but path-creation is not possible due to institutional, infrastructural, behavioral, and discursive lock-in mechanisms. All four lock-in types reinforce each other and partly overlap (Klitkou et al. 2015; Seto et al. 2016). Path dependency and lock-in are neutral terms that describe systemic processes that serve to maintain the status quo. The concept of carbon and methane lock-in refers to systems based on the use of fossil fuels. It explains the persistence of fossil fuel-based technological systems despite their well-known negative climate impacts as well as the prevention of the implementation of renewable alternatives (Unruh 2000).

1.2.4 Regime actors

Actors and their interests are regarded as important elements of transition research. This is reflected in the increasing number of scientific papers published on the subject (Fischer and Newig 2016). Actors are important since they have agency and can shape the unfolding energy transition. With regard to path dependency and carbon and methane lock-in mechanisms, incumbent actors are particularly interesting because they have an interest and the capacity (e.g., resources, strong network positions, influence on political agenda setting) to maintain the status quo and slow down transition processes (Lockwood, Mitchell, and Hoggett 2019; Galeano Galvan, Cuppen, and Taanman 2020). Incumbent actors are not necessarily companies, but can belong to very different actor groups from business, politics, and society (Turnheim and Sovacool 2020). Consumers, for example, can thus also act as incumbent actors. Regime actors differ from incumbent actors in the sense that a regime actor can take on a variety of roles and, for example, also contribute to a regime change (F. W. Geels 2021; Mori 2021; Turnheim and Sovacool 2020). Therefore, a differentiated classification of actors based on their actual orientation is necessary for a scientific analysis.

Energy transitions literature increasingly includes power and politics aspects and deals with incumbents of regimes. More specifically, it engages with the question how particular actors, such as incumbent corporations as well as policymakers, use their power to resist or slow down changes (Lockwood, Mitchell, and Hoggett 2019; Kern, Kivimaa, and Rogge 2017; Johnstone, Stirling, and Sovacool 2017; Kungl 2015; F. W. Geels et al. 2016). However, the role of incumbent actors in the activation of carbon and methane lock-in mechanisms has not yet been sufficiently addressed. In this dissertation I address this research gap and contribute to the meta-theoretical framework of co-evolving systems by including the role of actors.

1.3 Frameworks and methods

To answer the research questions raised in chapters 2-5, research designs applying different frameworks and research methods were developed in the individual chapters (see Table 1). In chapters 3 and 5, two different frameworks were used to make the cases workable by structuring reality and identifying relevant variables to guide data collection. In addition to the different methods of data collection, an actor analysis (chapter 3) and the case study approach (chapters 3-5) were applied. This section provides an overview of the different frameworks and methods. How they were applied in detail is explained in the respective chapters.

1.3.1 Co-evolving systems

The section on path dependencies and lock-ins has shown that the analysis of these phenomena requires an interdisciplinary approach. Furthermore, the focus of the analysis should not only be on the socio-technical niche or regime, as in the case of MLP, but should take into account a range of factors that can influence energy transitions and lead to carbon and methane lock-in mechanisms. The question in chapter 3 also includes the analysis of the role of actors for the activation of lock-in mechanisms. Therefore, in the first part of this paper, a meta-theoretical framework was applied that covers political, technological, and economic developments relevant for the energy transition. This allowed for an interdisciplinary analysis that includes factors that go beyond a focus on the relationship between the niche and the regime. Furthermore, the framework is open for the inclusion of actors.

The meta-theoretical framework conceptualizes national energy transitions as unfolding in three autonomous but co-evolving systems: a) policy system (composed of political actions and policies), b) techno-economic system (composed of energy flows and markets), and c) socio-technical system (composed of energy technologies and artefacts, businesses and practices) (Cherp et al. 2018). With reference to Ostrom's (2005) research, all three systems are described as semi-autonomous with their own elements, boundaries, and dynamics. While all three systems can develop independently of each other, they also interact, and hence co-evolve and share certain elements. One and the same real-world object can be part of one or more systems and a single actor can play a different role in each system. Hierarchically organized variables are assigned to the three systems, providing clear guidance for analysis. This was also an important criterion for the decision to use the framework due to the complexity of the research objective. The development of the variables within the systems and the interaction of the three systems can explain the course of energy transitions. The framework enables the identification of mechanisms affecting one or several of the three systems, explaining courses of change or lock-in.

An important theoretical question is how this co-evolution of the different systems takes place. An explanation offered by Cherp et al. (2018) is that there are artefacts that play a role in more than one system and thus create a link. This was not a sufficient explanation for the analysis in chapter 3. Therefore, I have integrated actors and their contribution to co-evolution into the framework (see Figure 3). This is because actors have agency and can influence and shape or slow down the course of energy transition, strategically using their resources for this purpose. Of particular relevance for the analysis were the strategies that actors use to assert their interests and how this leads to lock-ins or a slowing down of the transition.

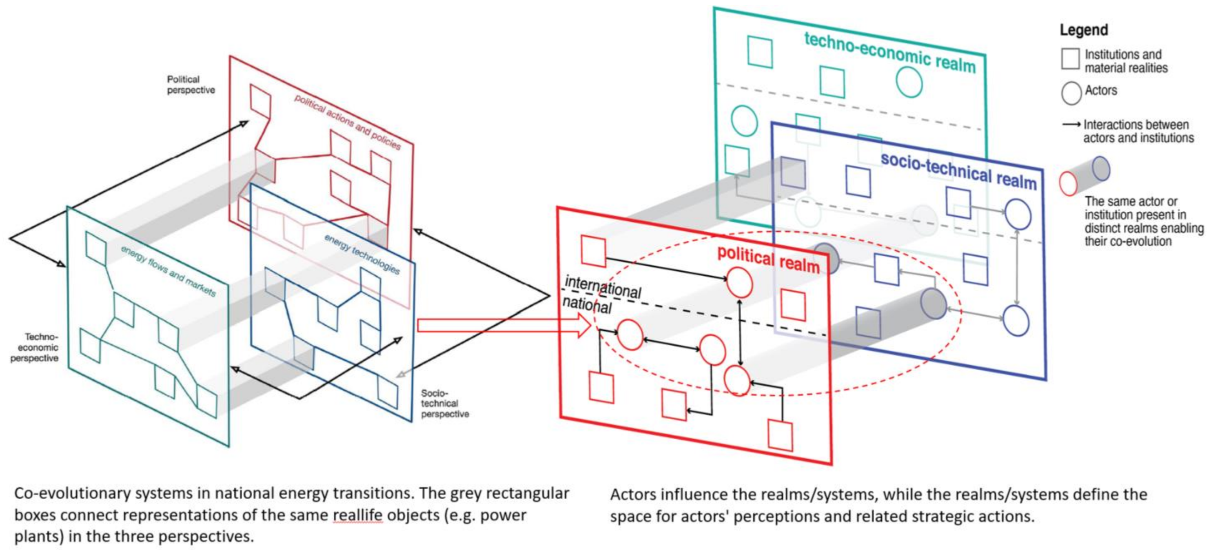

Figure 3: Actors enabling the co-evolution of the three systems

Source: Own depiction based on Cherp et al. (2018).

1.3.2 Collaborative governance

Chapter 5 deals with the question of how a political process must be designed in order to overcome the resistance of incumbent actors to a transition. The object of the analysis is the German stakeholder commission on phasing out coal. The core of the research question lies in the field of political science, which is why a combination of concepts from both transition research and political science was beneficial for building the research design. This dissertation contributes to sustainability transition research by transferring a framework from political science to the research field of transition studies.

The chapter draws on insights from collaborative (or participatory) governance (CG) research. So far, CG approaches have been used mainly to address resource and environmental conflicts (Ansell and Gash 2007; Emerson, Nabatchi, and Balogh 2012; Newig et al. 2018a). However, the Commission can also be viewed as an example of a CG approach. Under certain conditions, collaborative governance approaches can contribute to overcoming carbon and methane lock-in mechanisms by providing different relevant actors with a space to exchange and agree on a common transition path (e.g., Emerson and Nabatchi 2015; Sabatier and Weible 2007). To overcome regime resistance and carbon and methane lock-in mechanisms, the design of the CG regime plays an important role in its success, as the right set-up enables a balancing of power asymmetries between actors. For such an analysis of the design of the commission, a framework was needed that would allow for a systematic and empirical assessment of CG processes and the inclusion of the concepts of lock-in and regime. Another requirement was transferability to the case of the Commission. Furthermore, it was important that contextual factors could also be included in the analysis. The integrative framework for collaborative governance by Emerson et al. (2012) meets these requirements. Additionally, the analysis benefits from the comprehensive range of literature on different forms of collaboration and collaborative processes which the framework builds on (e.g. Ansell and Gash 2007; Innes and Booher 1999).

According to Emerson et al. (2012), collaboration dynamics lie at the heart of the collaborative governance regime. They can lead to collaborative actions or outputs, such as policy advice. They consist of principled engagement, shared motivation, and capacity for joint action, which are in iterative interaction with each other. Each collaboration dynamic comprises further elements. Principled engagement relates to an effective engagement of all participants, enabling fair and inclusive discussions and decision-making among participants. It comprises the four elements discovery, definition, deliberation, and determination. Shared motivation, with the four elements trust, mutual understanding, internal legitimacy, and commitment, fosters participants' engagement with each other and the CG process. The functional dimension capacity for joint action enables participants to accomplish their collective purpose and is conceptualized as the combination of four elements: procedural and institutional arrangements, leadership, knowledge, and resources (Emerson, Nabatchi, and Balogh 2012). Based on the analysis of these elements, considering the system context, it can be evaluated to what extent the set-up of the collaborative governance regime enabled the development of collaborative governance dynamics and thus contributed to overcoming a lock-in situation in the transition process.

1.3.3 Case study

A case is an analytical construct that narrows down an object to the aspects relevant to the research question and thus breaks down reality to a workable level of knowledge (Lund 2014). A case study is an intensive study of a single case or a comparative study of a small number of cases. Identifying and understanding carbon and methane lock-in mechanisms of natural gas from various perspectives, taking into account actors and looking at different relevant sectors, is a complex undertaking. The same applies to the evaluation of governance strategies, which requires a thorough understanding of the institutional framework, the actors and actor groups involved, and (especially in the case of behavioral path dependencies and lock-ins) the cultural and historical context. In order to do this complexity full justice, an in-depth single case study for the case of Germany is conducted in the chapters 3-5. Due to its characteristics as an extreme case (see section 1.1.4), it can be assumed that path dependencies of all types exist, that lock-in mechanisms are active, and that the relevant actors are already activated. This makes Germany an interesting object of in-depth analysis, able to reveal valuable information on the logic of lock-in mechanisms (Flyvbjerg 2006).

1.3.4 Actor analysis

In order to implement a transparent and structured analysis of relevant actors and their role in the emergence or reinforcement of path dependency and carbon and methane lock-in mechanisms, a stakeholder analysis is conducted in the first part of this thesis. This method originates from health research (Brugha and Varvasovsky 2000). As transition literature uses the term "actor" instead of "stakeholder", this dissertation uses the term "actor analysis" to avoid confusion. Actor analysis is an approach for generating knowledge about actors and can be used to understand their behavior, motivation, intention, inter-relation, and interests, as well as to assess their influence and resources they can use in policy-making processes (Brugha and Varvasovsky 2000). Actor analysis as a methodology has been criticized for a lack of rigid criteria according to which actors are included or excluded from the analysis (Reed et al. 2009a). Therefore, the approach is described as transparently and in as much detail as possible in chapter 3.

1.3.5 Data collection

Extensive data collection took place within the scope of the individual research projects. The collected data was evaluated and cross-checked during the collection process and data collection continued until a certain degree of saturation was reached. In other words, data was collected until information became increasingly predictable, and surprises petered out (Lund 2014).

1.3.5.1 Material analysis

Scientific articles as well as other data sources such as studies, government documents and legal texts were collected and analyzed for the individual chapters. The information gained from the material analysis was used, on the one hand, to develop questionnaires and to contextualize the collected data from the interviews. On the other hand, it served to tailor the interview questions to specific actors/interviewees. In addition, the data was used to provide background information on the case, to provide historical context, and to track changes and developments over time (Bowen 2009). The identification of each data source and how it was used is described in each chapter.

1.3.5.2 Integrated literature review

In many research areas, knowledge production advances at an enormous speed, while the interdisciplinarity of studies also increases. Due to this development, it becomes more and more difficult for researchers to keep track and stay up to date with the state of the art in research. The literature review as a research method is therefore gaining importance. Depending on the chosen approach, a literature review is a more or less systematic way of collecting and summarizing previous research findings (Snyder 2019). An integrative literature review is a form of review with the aim to provide new perspectives by critically reviewing, analyzing, and synthesizing representative literature on a topic. The capacity of an integrative literature review to generate new ideas and directions for the field is the strength of this research method (Torraco 2005). This type of review usually does not aim to cover all articles ever published on the topic, but rather to combine perspectives and findings from different fields or research traditions (Snyder 2019). In chapter 2, this is ensured as the authors of the chapter have different disciplinary backgrounds (political science, sociology, economics, and engineering). All of them have conducted research on the topic of natural gas in the past and were thus able to contribute an initial base of relevant literature.

1.3.5.3 Semi-structured expert and stakeholder interviews

In chapters 3-5, own data was collected in addition to the material analysis. For this purpose, interviews were conducted with relevant stakeholders and scientific experts or practitioners. In all cases, it was important to deal with several topics – not determined by the answers of the interviewees, but by the research objective – which is why semi-structured interviews were chosen as a means of data collection (Gläser and Laudel 2010a). During the development of the interview guidelines, care was taken to raise a broad spectrum of issues in order to give the interviewees as much room as possible to present complex interrelationships. The guidelines were tailored to each interviewed actor or actor group, adapting to the level of knowledge of the interview partners. The professional context of the interviewees was taken into account both in their selection and in the interpretation of their answers.

Following Gläser and Laudel (2010a), different questioning techniques were used for individual interview situations and research interests. For example, the expert interviews consisted mainly of factual questions, while opinion questions were mostly omitted, unless it was a stakeholder whose personal opinion or motivation was relevant for answering the research question. Detailed questions were largely avoided in favor of open questions. In some cases, the guidelines contained back-up questions in case the answers of the interview partners did not address all aspects relevant to the research question. A preliminary version of the guidelines was presented to internal and external experts with appropriate disciplinary and methodological backgrounds. Their feedback was incorporated and a test run was carried out. This process was repeated until the guidelines met the requirements of the research question and the research design. The selection process of the individual interview partners is described in the respective chapters. Where possible, several persons with a similar context were interviewed to be able to triangulate the information.

1.3.5.4 Background interviews

In Chapters 3 and 4, in addition to the semi-structured expert interviews, background interviews were conducted. Background interviews were used to obtain specific information, usually from academic experts whose knowledge was not necessary to answer the research question but who could clarify details such as specific technical or institutional issues or provide contextual information such as expertise on other cases. For each background interview, concrete questions were developed to obtain specific expert knowledge from the interviewee. This information was then used in the development of interview guidelines or the preparation of the manuscript, but was not formally analyzed using the coding scheme.

1.3.6 Data analysis: qualitative content analysis

The data collected in chapters 3 to 5 is analyzed with the help of qualitative content analysis based on Gläser and Laudel (2010a). According to this method, raw data is extracted from the interview transcript, processed, and evaluated. The interpretation of the extracted text sections takes place independently of the text as a whole. The extraction is carried out using a system of categories that is constructed based on theoretical considerations, the applied frameworks, and content-related preliminary work in the respective chapters. The evaluation method according to Gläser and Laudel (2010a) differs from other approaches insofar as the category system remains open and can be supplemented during the extraction process if information emerges from the data that is relevant for the analysis but cannot be classified in the existing categories. The raw data is then summarized, checked for redundancies and contradictions, and structured. The information obtained on the individual categories is then evaluated to answer the research question.

1.4 Outline of the dissertation

1.4.1 Part 1: Path dependencies from natural gas and the resulting risk of lock-ins

1.4.1.1 Chapter 2: The expansion of natural gas infrastructure puts energy transitions at risk

Despite growing concerns about the negative impacts of natural gas, both production and consumption have continued to increase globally in recent years (IEA 2021a). Consequently, CO_2 emissions related to natural gas grew by 2.6% annually between 2009 and 2018 (Peters et al. 2020). The continued investments in natural gas infrastructure have been justified by promoting natural gas as beneficial for the transition to renewable energy sources and a massive expansion of natural gas infrastructure is currently underway (Tanaka et al. 2019; I. A. G. Wilson and Staffell 2018; IEA 2011). In an interdisciplinary approach, this chapter argues from five different perspectives why the expansion of natural gas infrastructure hinders a renewable energy future and why the natural gas bridge narrative is misleading. The chapter highlights that the climate impact of natural gas has previously been underestimated and that recent insights have not been sufficiently incorporated into energy system analyses. At the same time, the bridge narrative is problematic. Investments in natural gas make it more difficult to achieve climate targets due to lock-ins and carry high economic risks.

This chapter proposes five ways to avoid common pitfalls for countries developing strategies for GHG reduction. First, the management of GHG emissions, especially that of methane leakage along the entire natural gas value chain, requires significant improvement. Second, to avoid misleading policies, the assumptions of scenario analyses need to be revised to include new research insights on GHG emissions related to natural gas. Third, narratives presenting gas as climate friendly need to be replaced with unambiguous criteria. Fourth, in order to meet climate targets, further lock-ins must be avoided. Finally, climate-related risks such as asset stranding need to be taken seriously in energy infrastructure planning.

1.4.1.2 Chapter 3: Liquefied natural gas expansion plans in Germany: The risk of gas lock-in under energy transitions

Chapter 3 highlights lock-in potentials and related emissions from natural gas which may complicate and decelerate energy transitions. The chapter analyses why political support for the construction plans of three large LNG import terminals in Germany is strong despite those plans being incompatible with national climate targets.[20] At the time of analysis, Germany already had extensive natural gas import capacities and construction of Nord Stream 2, a natural gas pipeline with even higher import capacities than the three LNG terminals combined, was well underway. The commissioning of the pipeline would have merely increased Russian imports of natural gas further. Against this background, the alleged possibility of diversifying natural gas imports through the operation of LNG terminals was not sufficient as an explanatory factor for the strong state support at that point in time.

[20] The analysis was conducted before Russia's attack on Ukraine and the resulting worsening of the energy crisis.

The meta-theoretical framework by Cherp et al. (2018) is used to structure the analysis. The focus lies on the role that actors play in the co-evolution of systems, how material developments within the systems are perceived by actors and influence their actions, and how this leads to carbon and methane lock-in mechanisms. A new 5-step approach is developed to triangulate material with an interview-based actor analysis. Through this, a wide variety of data (documents and interview data) can be used to cover both the three systems and actors' perceptions to analyze the resulting mechanisms influencing energy transitions.

The results show that four natural gas lock-in mechanisms cause the support for the construction of LNG terminals in Germany: (1) the geopolitical influence from the United States; (2) security of supply concerns due to the planned coal and nuclear phase-out; (3) pressure from a wide variety of state and private sector actors; and (4) sunk investments in existing gas infrastructure. Two additional mechanisms supporting the strong position of natural gas are the strength of the emerging synthetic gas niche, and weak opposition against LNG and natural gas.

1.4.2 Part 2: Governance strategies for overcoming path dependencies and preventing lock-ins from natural gas

1.4.2.1 Chapter 4: Communal heat planning: Overcoming the path dependency of natural gas?

To phase out natural gas, decarbonizing low-temperature heat, which accounts for around 40 percent of the total natural gas consumption in the EU,[21] is of central importance. To provide low-temperature heat to EU consumers, the Member States operate a natural gas distribution network with a combined length of around 2 million kilometers. In order to prevent a lock-in of natural gas in residential heat and to minimize negative effects on operators and consumers, a clear long-term strategy for the gradual decommissioning of a large part of this infrastructure is essential. Even though the heat transition is receiving increasing scientific and political attention, the question of the future of natural gas distribution networks has not yet been sufficiently addressed. Chapter 4 aims to fill this gap in showing to what extent the instrument of municipal heat planning is suitable to overcome path dependencies caused by distribution networks. Several German states are currently promoting communal heat planning. The chapter focusses on Baden-Württemberg, the most advanced state in this respect. The analysis is based on 20 interviews with representatives of the most relevant stakeholder groups.

The chapter concludes that municipal heat planning can help overcome some institutional path dependencies, such as the planning deficit in the heat transition. It can also help improve access to necessary data, incentivize the development of personnel capacities, and support knowledge building for the heat transition at a municipal level. It also enables the involvement of local stakeholders. In order to implement the heat transition and overcome path dependencies from the natural gas distribution network, additional policy measures are necessary. The results show that the greatest risk of a natural gas lock-in lies in the behavioral dimension, which has so far received the least attention in the literature on carbon and methane lock-ins. The chapter stresses that the success of the heat transition strongly

[21] ACER. 2022. Op. cit.

depends on understanding behavioral path dependencies and finding effective strategies to overcome them. The heat transition depends on individual decisions made by many different homeowners and will entail changes in the private sphere as well as adjustments in the everyday working lives of many professional groups.

1.4.2.2 Chapter 5: Overcoming political stalemates: The German stakeholder commission on phasing out coal

The transition in the electricity sector in Germany is already well advanced compared to that in the heating sector. In 2000, the Renewable Energies Act gave a political impetus to the expansion of renewable energies, and installed generating capacity has been continuously growing ever since. However, a transition also requires the closure of fossil power plants. In the case of lignite in Germany, this also includes the associated opencast mines. This step was highly controversial and met with fierce resistance from various influential stakeholder groups. This led to a political stalemate situation, stalling the transition process.

This chapter analyses how this stalemate situation in the German conflict over the future of coal was overcome. In 2019, the Commission on Growth, Structural Change and Employment was set up to propose, develop, and pass recommendations for a just transition away from coal. As the Commission included most relevant stakeholders, its recommendations were supported by all influential actors and thus achieved a high level of legitimacy. The Commission enabled the development of joint recommendations and helped overcome a long-standing stalemate situation by providing a safe space to build up trust and understanding. This was important considering the highly contentious situation. The broadly worded mandate and the provision of federal funds largely defined the possible solution space for the Commission. The political and economic pressure and absence of other alternatives contributed to actors' willingness to engage in the Commission and to find common ground. Critical aspects concerning the design of the Commission are that existing power imbalances have not been sufficiently addressed. This had an impact on the capacities of different members to participate and resulted in the decision-making process being dominated by certain members. The findings can inform similar stakeholder commission processes taking place in other countries or dealing with other unresolved issues, such as the future of natural gas in the heating sector.

1.4.3 Overview of the chapters: research questions, methods, frameworks, and scientific contributions

Table 1 gives an overview of the two parts of the dissertation and the corresponding chapters, their research questions as well as the applied methods and frameworks. Furthermore, the table summarizes the scientific contributions of each chapter.

Part	Chapter	Research Question	Applied Framework and Methodology	Scientific Contribution
Part 1: Path dependencies from natural gas and the resulting risk of lock-ins	Chapter 2: The expansion of natural gas infrastructure puts energy transitions at risk	**RQ1:** Do current global developments in natural gas infrastructure expansion create a risk for sustainable energy transitions?	▪ Integrative literature review ▪ Material analysis	▪ Identification of five common misconceptions that lead to an overly positive assessment of the role of natural gas for the transition. ▪ Analysis of the role of natural gas for the energy transition from different perspectives. ▪ Stimulate and broaden the scientific debate on the role of natural gas in the energy transition.
	Chapter 3: Liquefied natural gas expansion plans in Germany: The risk of gas lock-in under energy transitions	**RQ2:** How do the material conditions around natural gas consumption and LNG infrastructure relate to and interact with actors' perceptions of these conditions? And how do these interactions shape systemic changes and create lock-ins for the German energy transition?	▪ Meta-theoretical framework of co-evolving systems ▪ Case study ▪ Actor analysis ▪ Material analysis ▪ Semi-structured expert and stakeholder interviews ▪ Background interviews ▪ Qualitative content analysis	▪ Further development of the meta-theoretical framework of co-evolving systems. ▪ Development of a methodological approach to combine an actor analysis with a material analysis. ▪ Identification of 6 mechanisms that explain the political support for LNG terminals in Germany.

Part 2: Governance strategies for overcoming path dependencies and preventing carbon and methane lock-ins	Chapter 4: Communal heat planning: Overcoming the path dependency of natural gas?	**RQ3:** Is municipal heat planning, as stipulated in the Climate Protection Act of Baden-Württemberg, a suitable instrument to overcome path dependencies through existing natural gas distribution networks and to implement a partial decommissioning of the networks?	▪ Case study ▪ Material analysis ▪ Semi-structured expert and stakeholder interviews ▪ Background interviews ▪ Qualitative content analysis	▪ Conception and application of an interdisciplinary approach for the analysis of path dependencies and lock-in effects. ▪ Analysis of the policy instrument of municipal heat planning for its potential to prevent possible lock-in effects through natural gas. ▪ Identification of path dependencies that are only partially or not at all addressed by municipal heat planning.
	Chapter 5: Overcoming political stalemates: The German stakeholder commission on phasing out coal	**RQ4:** How can a political process be designed and managed to achieve a coal phase-out in the event of incumbent actors blocking coal phase-out policies?	▪ Integrative framework for collaborative governance ▪ Case study ▪ Material analysis ▪ Semi-structured expert and stakeholder interviews ▪ Qualitative content analysis	▪ Transfer/application of a political science framework to transition research. ▪ Systematic analysis of the Commission's internal work processes and the development of the joint recommendations. ▪ Identification of drivers for compromise in the coal phase-out. ▪ Transfer of the results to other transition processes.

Table 1: Overview of the chapters, research questions, the applied methods, frameworks, and scientific contributions.

1.4.4 Overview: Chapter origins and own contributions

Table 2 provides an overview of the individual chapters by publication status as well as authorship and the contribution of the individual authors.

Chapter	Pre-publication and own contribution
2	**The expansion of natural gas infrastructure puts energy transitions at risk**
	Published as: Kemfert, Claudia; Präger, Fabian; Braunger, Isabell; Hoffart, Franziska and Brauers; Hanna. 2022. „The expansion of natural gas infrastructure puts energy transitions at risk“. *Nature Energy* 7 (July): 582–87. https://doi.org/10.1038/s41560-022-01060-3.
	Joint work with Claudia Kemfert, Fabian Präger, Franziska Hoffart and Hanna Brauers. The conceptualization was conducted jointly. Formal analysis was conducted with Fabian Präger and Franziska Hoffart. The manuscript was written jointly with Fabian Präger, Franziska Hoffart and Hanna Brauers.
3	**Liquefied natural gas expansion plans in Germany: The risk of gas lock-in under energy transitions**
	Published as: Brauers, Hanna; Braunger, Isabell and Jewell, Jessica. 2021. „ Liquefied natural gas expansion plans in Germany: The risk of gas lock-in under energy transitions“. *Energy Research & Social Science* 76 (June): 102059. https://doi.org/10.1016/j.erss.2021.102059
	Joint work with Hanna Brauers and Jessica Jewell. The conceptualization, methodology investigation, interviews, and formal analysis were conducted jointly with Hanna Brauers. The manuscript was written jointly with Hanna Brauers and Jessica Jewell.
4	**Communal heat planning: Overcoming the path dependency of natural gas?**
	Under review at *Environmental Innovation and Societal Transitions* (03/2022)
	Single author original research article
5	**Overcoming political stalemates: The German stakeholder commission on phasing out coal**
	Submitted to *Energy Research & Social Science* (02/2023)
	Joint work with Christian Hauenstein, Alexandra Krumm, and Pao-Yu Oei. The authors contributed equally to this work: Conceptualization, methodology, interviews, formal analysis and writing of the manuscript. Christian Hauenstein provided the project administration.

Table 2: Chapter origins and own contributions.

1.5 Policy recommendations

In the following, six key findings from this dissertation are highlighted that could be particularly relevant for policy makers to consider when assessing the benefits of infrastructure projects for the energy transition, potentially reassessing natural gas and its contribution to the transition process, and successfully governing the phase-out of natural gas.

1.5.1 Natural gas consumption bears a high lock-in risk

Natural gas is a climate-damaging energy source and does not provide a solution towards a zero-emission future (see chapter 2). Chapter 2 and 3 show that natural gas poses a high lock-in risk that can slow down the energy transition process. To achieve the climate targets laid out in the Paris Agreement, a natural gas phase-out is unavoidable. In order to avoid methane and carbon lock-in mechanisms and to effectively govern the energy transition away from natural gas, existing path dependencies must be identified and politically addressed to the greatest possible extent. This requires a holistic assessment that takes into account all four types of path dependency instead of merely infrastructure. Path dependency and lock-in mechanisms must be considered when planning the expansion of natural gas infrastructure, especially if the expansion is being legitimized with plans to replace natural gas with synthetic gases or e-fuels in the long term. The current energy crisis presents a crossroad in the phase-out of natural gas, where either lock-in mechanisms can be activated or new paths can be created that advance the transition.

1.5.2 Early planning of the natural gas phase-out can help avoid lock-ins

The narrative of the “bridge technology” is not a suitable guide for the future role of natural gas in the transition. The narrative remains vague at relevant points and actors have different visions and interpretations of future developments based on their own interests, as shown in chapter 3. In order to create commitment and planning certainty, the “bridge” narrative needs to be replaced by a phase-out concept including clear criteria and yearly limits for greenhouse gas emissions from natural gas depending on application. Chapter 2 illustrates that for such a concept to lead to compliance with climate targets, energy scenarios used for planning must include the latest scientific findings on methane emissions. This implies that all emissions occurring along the chain of natural gas production and consumption must be considered and that the latest research findings on the climate impact of natural gas must be taken into account. In order to improve the database for such scenarios, it is crucial to conduct comprehensive measurements along the value chain. Since methane is a short-lived climate gas, it is important to consider both the 20-year and 100-year time horizons.

1.5.3 Recalibration of the relationship between security of supply and climate protection

Future infrastructure investments need to be strictly aligned with climate policy targets and not merely seen through the lens of security of supply. However, in planning and implementing new natural gas infrastructure, the focus has so far been largely on security of supply questions. For instance, regulations for investments in natural gas distribution network infrastructure in Germany do not take climate targets into account (see chapter 4). A recalibration of the relationship between the two policy goals can help avoid an increasing natural gas lock-in and its resulting negative economic and ecological impacts. Especially in times of crisis, it is important to jointly consider the two policy goals and to favor solutions that contribute to the achievement of both goals in the long term. Otherwise, natural gas could crowd out investments in renewables and thereby slow down the shift to low-carbon energy sources as well as the reduction of the import dependency from fossil fuels.

1.5.4 Participation of actors in transition processes can help circumvent lock-ins

Key actors and their perceptions of material reality play an important role in the activation of lock-in mechanisms (see chapter 3). Actors can use their resources to slow down the transition if they see their own interests at risk or interpret material developments in line with their own interests and act accordingly. With their actions, they in turn create material realities that can reinforce path dependencies or even lead to a carbon and methane lock-in. For instance, if actors assume that natural gas will again be available at favorable prices in the future, they will develop different action strategies compared to a situation in which there is an expectation that natural gas will be scarce and expensive in the medium to long term. For this reason, relevant actors from all stakeholder groups and their interests should be identified, considered, and addressed when governing the transition process. An early involvement of stakeholders can also help accelerate the transition. This requires appropriate governance instruments such as municipal heat planning. Therefore, municipalities must be provided with the necessary resources, capacities, and know-how for a successful participation process (see chapter 4).

Collaborative governance approaches also have the potential to bring relevant stakeholders together and to create a trustful environment in which actors can identify win-win situations and jointly shape the transition. Such approaches are particularly suitable when the pressure for change is high among all stakeholder groups, creating a willingness for compromise. In order to leverage the advantages of such a setting and to develop collaborative dynamics, appropriate structures for balancing power asymmetries should be created (see chapter 5). A prior political decision-making process for initiating a transition is a central condition for the success of a collaborative governance process. In the case of the natural gas phase-out, this condition is not yet met. There are still too many disagreements and uncertainties, for example with regard to synthetic gases, for there to be the possibility of finding a compromise for a natural gas phase-out at the national level. However, there is potential for the implementation of collaborative governance regimes at the regional level, when it comes to the preparation or implementation of heat plans. Here, the inclusion of stakeholders, for example through a commission, can certainly help overcome path dependencies and can have a legitimizing and possibly accelerating effect.

1.5.5 Unconsidered behavioral path dependencies can slow down the transition

Chapter 4 points out that there is a high carbon and methane lock-in potential in the heat transition due to entrenched behavioral structures. The heat transition depends on the individual decisions made by many different actors. It will entail changes in the private sphere (the home) and consumption patterns. Furthermore, it requires adjustments in the everyday working lives of many professional groups such as service providers and craftsmen. They have knowledge and skills to produce, sell, install, and maintain known (fossil) systems. An increasing demand for renewable technologies, such as PV systems or heat pumps, may therefore be faced with the problem of the workforce being too small to supply these systems at a sufficient scale. This is not only due to a possible lack of economic incentives for companies to adapt their services, but also to a reluctance to gain new knowledge (especially among older skilled workers). This is therefore a behaviorally induced cause of path dependency. A rapid implementation of the heat transition depends strongly on understanding behavioral path dependencies and finding effective strategies to overcome them. The timely development and implementation of such strategies is of great importance, as behavioral path dependencies sometimes persist over longer periods than path dependencies of institutional or technical origin.

1.5.6 Expertise and responsibilities at regional level are important for the heat transition

The success of a natural gas phase-out is closely linked to the progress of the heat transition, which must be planned and implemented at the local and regional level. Even though the instrument of municipal heat planning offers guidance, there is often a lack of expertise at the municipal level to evaluate and adequately address the technical, economic, and social dimensions of such a major task (see chapter 4). A relevant example is the uncertainty surrounding the question of whether and under what conditions hydrogen use for low temperature heat provides a reasonable alternative to natural gas. Another example is the development of new economic concepts and fields of activity for municipal utilities. Financial resources must be made available at the local or regional level to employ professionals who, on the one hand, have the necessary expertise to coordinate a sound heat planning and, on the other hand, have clear responsibility for implementing, monitoring, and steering the heat transition.

1.6 Shortcomings

In the following, overarching shortcomings are presented in order to paint a clearer picture of the strengths and weaknesses of this work.

1.6.1 Comparative approach to analyze natural gas phase-outs

Path dependencies through natural gas materialize differently from context to context. For example, institutions, infrastructure, and actor landscape differ strongly between cases. Accordingly, strategies to overcome path dependencies have to be developed in context-specific ways. This makes it difficult to generalize findings and transfer them from case to case or over time. Nevertheless, results from different cases can be triangulated to test the robustness of findings and learn more about the functional logic of carbon and methane lock-ins. For instance, in the case of path dependencies in the use of natural gas, a comparison with the case of the Netherlands, where a natural gas phase-out has already been decided and strategies for implementation such as communal heat planning are currently being developed, could produce insightful outputs. A comparison of the developments in the heat transition of Germany and the UK could also yield valuable insights. Both countries have a relatively large natural gas distribution infrastructure whose future use is currently under discussion. Hence, a shortcoming of this dissertation is that the empirical findings of the German case could not be extended by means of a comparative study.

1.6.2 Data basis for a politically induced natural gas phase-out

The (politically induced) gas phase-out is not as far advanced as the coal phase-out. In most European countries, it is currently at an early stage. Accordingly, there have been relatively few scientific analyses of possible governance strategies so far. In this dissertation, the analysis of municipal heat planning in Baden-Württemberg as an instrument to overcome path dependencies took place while the development of heat plans was still ongoing. This limitation of the research object could possibly be circumvented by taking into account historical heat transitions. However, this poses the question of whether findings from different historical contexts can be transferred to current heat transition processes. For example, the switch from oil to natural gas and biomass in the heating sector in Denmark was economically induced by the oil crisis. The tense situation on the oil market put pressure on incumbent actors, making policy measures easier to implement than in the case of a stable existing regime. Nevertheless, it can be worthwhile to use findings from historical heat transitions that were economically rather than politically induced to expand the data base and generate additional insights for the heat transition, especially in the context of the ongoing natural gas crisis.

1.6.3 The energy crisis could not be considered

When working on very current topics, such as transitions in process, there is always the risk of landscape shocks leading to completely new, unforeseeable developments that overtake current research. Russia's invasion of Ukraine and the resulting energy crisis is an example of such a landscape shock. As explained in section 1.1.5, a natural gas phase-out is still not a given and the reinforcement of existing path dependencies and possible resulting lock-in effects can prevent or slow down the transition. However, the energy crisis persists, and its unfolding depends on various unpredictable factors such as developments on the LNG market, the perception and assessment of the situation by various actor groups and their response strategies, or the reliability of Russian natural gas exports. A worsening of the crisis and a possible gas shortage in the 2023/24 heating season could have far-reaching consequences and increase the pressure on actors to such an extent that path creation could take place more quickly than without a landscape shock. Possible developments in this direction must be the subject of further scientific work.

1.6.4 Development of the theorization of the lock-in concept

The term lock-in is used in many studies, as shown by comprehensive literature reviews (e.g. Fisch-Romito et al. 2021; Seto et al. 2016). Accordingly, comprehensive empirical studies and data exist as well, albeit so far less on natural gas and only to a limited extent on heat transitions. Although this dissertation makes a contribution in this area and provides initial insights on the role of actors in the activation of lock-in mechanisms, a positioning of the findings in an overarching theoretical and conceptual systematization is not possible, as such a theoretical synthesis of the findings does not yet exist. Although there are some important contributions in this regard (Seto et al. 2016; Unruh 2000), an evaluation and systematization of the current literature on all lock-in types that integrates findings from economics, political science, discourse analysis, and behavioral research has not yet been done and could not be provided within the scope of this work.

1.7 Research outlook

The potentially detrimental impacts of fossil natural gas as well as the constraints on security of supply that have become visible as a result of the energy crisis emphasize the need for research on how to achieve a 100% renewable energy supply while strictly minimizing natural gas use during the transition period. Before the energy crisis, natural gas was still considered a bridge technology and a phase-out was not under discussion. This is especially the case for Germany, where instead of a gas phase-out, the conversion from oil and coal stoves to natural gas in the provision of building heat was actually incentivized through financial subsidies. This situation has changed since the energy crisis and there is a great need to accelerate the heat transition, where transition research can make a valuable contribution. Some open questions are identified in the following research outlook.

1.7.1 Discourse shift due to the energy crisis

On a discursive level, a narrative can become hegemonic and impede path-creation on a material level (Buschmann and Oels 2019). In the discourse on the role of natural gas in energy transitions, the narrative of the bridge technology has become established and strongly shaped the public and political debate prior to the energy crisis (see chapters 2, 3, and 4). The energy crisis can be understood as a so-called discursive event (Jäger 2000), or, in the language of transition research, as a landscape shock. Such an event can lead to a shift in the discourse and the establishment of a new narrative. Discourse analysis can be used to study whether and in what form a discourse shift has taken place in the public, political, or scientific debate. A discourse analysis could also show what impact particular discourse strands such as the discourse on hydrogen or LNG have played in a possible discourse shift. Furthermore, information about which actors or actor groups have participated in the discourse and whether they formed discourse coalitions could be provided. From here, possible communication strategies for a natural gas phase-out can be derived.

1.7.2 Actor analysis of the heat transition

Stakeholders have agency and therefore play a central role not only in reinforcing path dependencies and the activation of carbon and methane lock-in mechanisms, but also in path creation. To overcome path dependencies and create new sustainable pathways, it is essential to identify the relevant active and inactive actors and their interests so that they can be included in path creation processes and addressed with appropriate policy measures.

This is relevant since even for the solution of what initially appears to be a purely technical problem, such as the decarburization of district heating, numerous actors must be identified and addressed and their interests and constraints must be taken into account. For example, producers of waste heat, such as data centers, need to be encouraged to enter the heat market, while at the same time new business relationships must be established between providers of waste heat and operators of district heating grids. This requires the collaboration of actors who have so far been unknown to each other. Appropriate conditions must be created for this to work smoothly. Another relevant stakeholder group for the decarburization of district heating networks is that of building owners. They need to be encouraged to insulate their building shells and install new heating systems if necessary. This means that many actors must be addressed whose motivations, possibilities, and limitations differ considerably (Engelmann et al. 2021). The complex interplay of different factors influencing homeowners in their investment decisions are insufficiently understood. A better understanding is necessary to enable a concrete approach and to set up targeted support programs.

In addition, an actor analysis can also identify where actors are missing who have the relevant know-how and interest in advancing the heat transition. For example, so far there are only a few actors who have an economic interest in a large-scale expansion of heat pumps or the construction and operation of short-distance heating networks. To date, there have been individual studies on specific actors (Agora

Energiewende 2019) or actor groups (Engelmann et al. 2021) and their interests, but no systematic assessment has been carried out.

1.7.3 The role of municipal utilities as central actors in the heat transition

In Germany, there are more than 1,000 municipal utilities with the central task of ensuring the basic supply of the local population with energy and heat. They are often the operators of distribution networks for electricity and natural gas as well as district heating networks. In addition, depending on the municipality, municipal utilities provide other services of public interest and finance these services through the profits generated from the energy sector (Schrems and Eulgem 2022). Already before the energy crisis, municipal utilities faced an enormous task. As central municipal actors, they were responsible for helping to shape the energy and heat transition, for example through implementing new infrastructure projects for the transition. At the same time, they were burdened with company restructuring and having to ensure the financing of other, less economic services such as public transport. The energy crisis places further limits on the investment possibilities of municipal utilities while making the urgency of transition even more evident.

What political support do municipal utilities need to be able to implement their own transitions from fossil-based business models to suppliers of renewable heat and electricity? What new business models and best practice approaches are there? How can employees who were previously involved in the planning and realization of natural gas networks or the marketing of natural gas services and supplies be trained to increase the currently low numbers of staff in the development of short-distance and district heating networks as well as in the marketing of heat network connections? These are just some of the questions that need to be answered in order to strengthen municipal utilities as central actors in the heat transition.

1.7.4 Analysis of municipalities with participatory structures for heat planning

In Germany, a federal law on municipal heat planning is currently under discussion which would obligate all federal states to undertake strategic heat planning. For the heat transition, it is advantageous to allow all relevant stakeholders across local, regional, and national levels to contribute their perspectives to the process and form coalitions. This way, cooperation comes to the fore rather than competition (Sovacool and Martiskainen 2020). The related discussion paper by the German Federal Ministry of Economic Affairs and Climate Action on the proposed law considers this aspect and provides for the participation of relevant stakeholders (BMWK 2022). However, how such participation would be implemented is not described in specific terms.

At this stage, the experience of the municipalities in Baden-Württemberg should be taken into account. A transdisciplinary and comparative analysis of different municipalities and districts that have established participatory structures in order to successfully include stakeholders in the planning process from the very beginning can provide important insights. This kind of analysis can provide answers to questions such as: Which structures have been created? Which actors have been involved? What was considered to be more or less helpful by different actors? What results were achieved and how realistic is the actual implementation of the heat plans by the municipalities?

1.7.5 Behavioral lock-in risks jeopardize the heat transition

While infrastructural and institutional lock-in mechanisms have been the subject of a large body of research (Fisch-Romito et al. 2021; Erickson et al. 2015; Unruh 2000), the state of knowledge on behavioral carbon and methane lock-ins is still comparatively thin (Seto et al. 2016). However, in order to implement the heat transition, related behavioral lock-ins must be better understood and subsequently addressed. For example, the transition requires many professional groups to acquire new expertise. It is possible that there is a behavioral lock-in here insofar as there might not be a willingness among the affected professional groups to do so. There is already a severe lack of skilled workers for the implementation of the heat transition.[22] Retraining opportunities should be designed in a low-threshold way so that the potential barrier to learning new skills is kept as low as possible.

Statistical data analysis can provide a good estimate of the size and skills of the existing workforce and potential training needs (Stephany and Luckin 2022). Qualitative analyses are needed to provide a better picture of the willingness and motivation of experienced workers to retrain and to identify factors that may prevent such willingness and lead to carbon and methane lock-ins. For individual technologies such as heat pumps, a comparative study or an in-depth analysis of cases where heat pumps have already been used on a large scale can provide valuable empirical data in this regard (Lauttamäki and Hyysalo 2019; Heiskanen, Lovio, and Jalas 2011; Hannon 2015).

1.7.6 Gender aspects of the heat transition

Sustainability transition processes cause far-reaching economic and social changes within societies. Historical analyses of coal transitions show that these changes do not affect all societal groups equally but interact with and potentially reinforce existing gender inequalities (Walk et al. 2021). A look at the renewable industry shows that gender inequalities are also at work here (Fraune 2015; IRENA 2019). When designing policy measures to implement sustainability transitions, gender aspects should therefore be taken into account to prevent inequalities from being reinforced or, at best, to use the potential of the transition to overcome these inequalities (Braunger and Walk 2022). So far, there are no studies that specifically look at the extent to which existing inequalities based on gender might be worsened by the ongoing heat transition. However, this is a precondition for developing gender-sensitive policies.

The limited research on the relationship between the heat sector and gender shows that gender does play a role here. For instance, women and men are being approached differently in the advertising of heating systems (Offenberger and Nentwich 2013). Depending on the location where the heating systems are to be placed, they are presented as facility management or home-making. The former, including heat pumps and solar panels, are assigned symbolic masculine values, while the latter, such as fireplaces, are advertised with female attributes (Röhr, Alber, and Göldner 2018). At the same time, sustainable energy solutions are limited to efficiency improvements and (renewable) technologies and thus fall into traditionally male-dominated areas, whereas other possible aspects of sustainability, such

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[22] Bundesagentur für Arbeit. 2022. “Fachkräfteengpassanalyse - Engpassberufe.” Accessed February 18, 2023. https://statistik.arbeitsagentur.de/SiteGlobals/Forms/Suche/Einzelheftsuche_Formular.html;jsessionid=8390EC74817846213243CD8EEE67FF78?nn=27096&topic_f=fachkraefte-engpassanalyse.

as social or behavioral aspects which are more associated with female attributes, are downplayed (Braunger and Hauenstein 2020).

The complex role of gender in socio-technical transitions is still rarely addressed or conceptualized, although interest in the topic has increased significantly in recent years (Braunger and Walk 2022; Wolfram and Kienesberger 2023). There is still a significant research gap regarding gender in heat transitions. Further research is necessary in order to inform political decision-makers and enable them to develop gender-sensitive measures for the heat transition.

Figure 4 provides an overview of the findings, shortcomings, and research outlook of the dissertation.

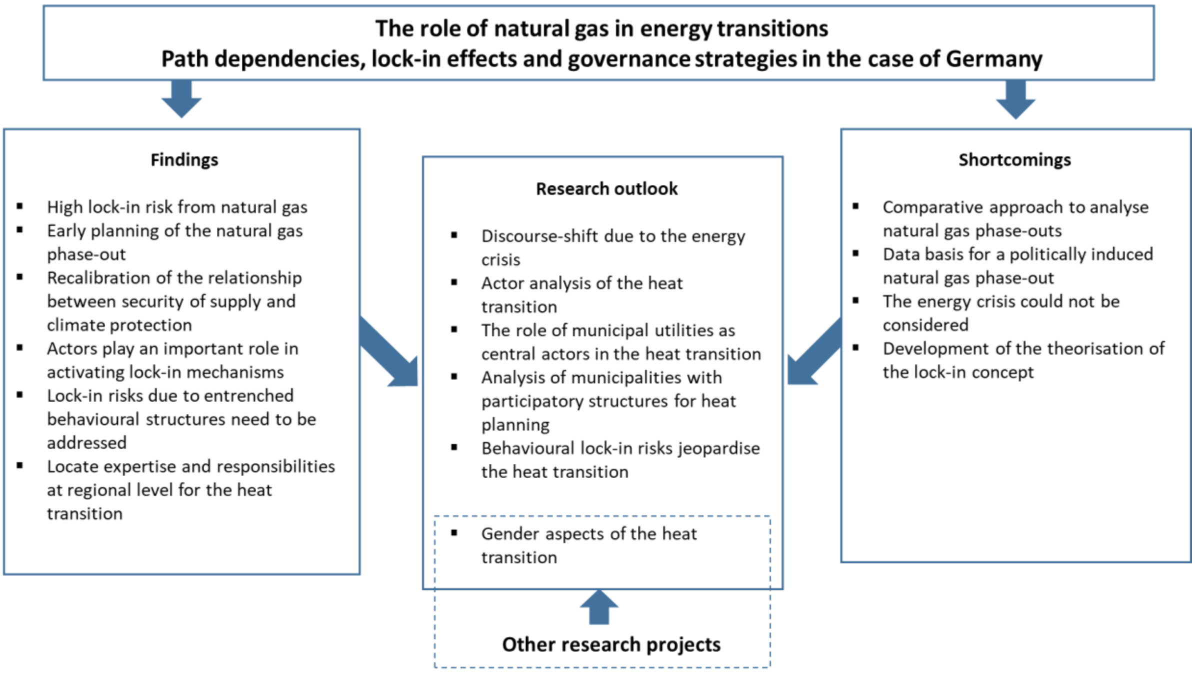

Figure 4: Overview of the findings, shortcomings, and research outlook of the dissertation.

Part 1
Path dependencies from natural gas and the resulting risk of lock-ins

2 Chapter 2: The expansion of natural gas infrastructure puts energy transitions at risk

2.1 Introduction

Despite growing concerns about the negative impacts of natural gas, its production and consumption experienced steep growth until the start of the COVID-19 pandemic (IEA 2021a).[23] Consequently, CO_2 emissions related to natural gas grew by 2.6% per year between 2009 and 2018 (Peters et al. 2020). Continuing investments in natural gas infrastructure have been justified by promoting them as beneficial for the transition to renewable energy sources and by presenting natural gas as a climate-friendly alternative to coal and oil (Tanaka et al. 2019; I. A. G. Wilson and Staffell 2018; IEA 2011). Globally, a massive expansion of natural gas infrastructure is underway: Almost 500 GW of natural gas-fired power plants are planned or under construction.[24] Meanwhile, new LNG import terminals with a capacity of 635 million tonnes of natural gas per year as well as LNG export terminals with a capacity of 700 million tonnes per year are under development.[25] These figures are likely to increase in the future, as a new geopolitical order has been created after Russia entering war with Ukraine. The EU is going to great lengths to become independent of Russian gas supplies, which still accounted for more than 40% of total gas imports to the EU by February 2022. Germany alone is responding to this new situation with a draft law approving up to 11 LNG terminals (7 offshore and 4 onshore units) under accelerated permitting procedures that can import fossil natural gas until 2043 (Deutscher Bundestag 2022).While these expansion plans will create new material realities, political and scientific controversy is growing about whether the use of natural gas and related infrastructure should be expanded. In light of climate protection goals, and the fact that natural gas itself is one of the biggest causes of climate change, questions now arise as to whether a rapid decline in natural gas use might be necessary, instead of expansion.

In this Perspective, we argue why the expansion of natural gas infrastructure hinders a renewable energy future and why the natural gas “bridge” narrative is misleading. Our aim is to stimulate critical discussion by challenging commonly held assumptions on natural gas. We highlight that the climate impact of natural gas has previously been underestimated and that new insights about this have not been sufficiently incorporated into energy analyses. At the same time, the “bridge” narrative is problematic. Meanwhile, investments in natural gas make it harder to achieve climate targets due to lock-ins, and carry high economic risks. Based on these arguments, we put forth five recommendations to stimulate debate on the role of natural gas in decarbonisation processes.

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[23] This chapter is published as Kemfert et al. (2022) in *Nature Energy* 7 (July). Joint work with Claudia Kemfert, Fabian Präger, Franziska Hoffart and Hanna Brauers. The conceptualization was conducted jointly. Formal analysis was conducted with Fabian Präger and Franziska Hoffart. The manuscript was written jointly with Fabian Präger, Franziska Hoffart and Hanna Brauers.

[24] S&P Global Market Intelligence. 2021. “World Electric Power Plants Data Base.” Accessed December 14, 2021. https://datasets.wri.org/dataset/globalpowerplantdatabase

[25] Global Energy Monitor. 2021. “LNG Export Capacity by Country.” Accessed January 3, 2022. https://globalenergymonitor.org/projects/global-gas-infrastructure-tracker/summary-tables/.

2.2 Methane emissions are much higher than previously estimated

In the public discourse, natural gas is often described as a climate-friendly alternative to coal that has a much lower negative climate impact than other fossil fuels (IEA 2011; Fitzgerald, Braunger, and Brauers 2019). In fact, several studies have shown that this is only true under certain conditions and that the differences in climate impacts are small and depend on various factors (Howarth 2014; Alvarez et al. 2012; Zhang, Myhrvold, and Caldeira 2014; Qin et al. 2018).

The extraction and use of fossil fuels accounts for about 15% to 22% of total methane emissions (Schwietzke et al. 2016). Along with natural and agricultural sources, it is one of the main sources of methane emissions that accumulate in the atmosphere. Latest research showed that the contribution of anthropogenic fossil-fuel sources to total methane emissions was underestimated in a range of 20% to 60% (Schwietzke et al. 2016; Hmiel et al. 2020). Natural gas consists largely of methane. The latest research on methane emissions related to natural gas production and transport has found that actual methane leakage rates far exceed previous estimates (Schwietzke et al. 2016; MacKay et al. 2021). However, there is no single, generally valid figure for fugitive methane emission rates related to the natural gas sector. This lack is due to the fact that the rate depends heavily on the individual technical characteristics and process-related factors of the gas system. However, regional studies on upstream methane emissions related to the oil and gas sector in Canada and the U.S. show that previous studies have underestimated methane emissions by 50% to 60% (MacKay et al. 2021; Alvarez et al. 2018).

The greenhouse gas (GHG) emissions advantage of natural gas over coal becomes marginal if approximately 3.2% (Alvarez et al. 2012) to 3.4% (Schwietzke et al. 2014) of the gas produced escapes into the atmosphere before being burned. The total global average leakage rate is estimated to be around 2.2% (Schwietzke et al. 2016). However, some studies investigating individual gas fields have even found fugitive emission rates of up to 6% of the total amount of natural gas produced (Hausfather 2015). Some measurements have even shown leakage rates of up to 17% for certain regions and circumstances (Caulton et al. 2014).

These high numbers can be explained by a small number of “superemitters”, which have leakage rates far above the average (Brandt et al. 2014). In addition to overall fugitive emission, unintended processing conditions along the supply chain of natural gas release huge amounts of methane from point sources. They are caused by malfunctions and equipment failures, and lead to disproportional emissions effects (National Academies of Sciences, Engineering, and Medicine et al. 2018). According to a study by Zavala-Araiza et al. (2017) on shale gas production sites in Texas, these superemitters account for approximately one-third of overall emissions released from shale gas production sites. Since these emissions occur from point sources that are increasingly easy to detect due to improved detection methods (satellites and remote sensors), these superemitter events might be controlled cost-effectively, avoiding large amounts of methane leaking into the atmosphere. Developing and implementing monitoring approaches that are able to detect superemitting events in a more timely manner, and thus reduce the frequency of large emission events, is a crucial first step for regulating methane emissions (2017). Nevertheless, considering the limited GHG budget left, such regulations – as well as leakage control – cannot replace a strong reduction in natural gas consumption: natural gas is still a fossil fuel that emits large amounts of CO_2 during combustion, in addition to fugitive methane emissions.

Furthermore, recent studies find that methane has a greater impact on the climate than previously assumed (Shindell et al. 2009; Myhre et al. 2013; Saunois et al. 2016). According to the latest figures by the Intergovernmental Panel on Climate Change, the global warming potential (GWP) of methane is up to 87 times greater than that of CO_2 in the first 20 years after emission, and up to 36 times greater in the first 100 years (Myhre et al. 2013). Given the high global warming potential of methane, especially in the first 20 years, the use of natural gas as a (temporary) substitute for coal may even lead to an additional short-term temperature increase (Zhang et al. 2016). As a result, the world could reach climate tipping points that could lead to abrupt and irreversible climate change as early as the next decade and, at worst case, trigger a cascade of global tipping points, leading to a “hothouse” scenario (Lenton et al. 2019). Consequently, short-term reductions of methane emissions are a crucial component of climate mitigation efforts.

2.3 Emissions from natural gas are poorly treated in scenarios

From a methodological perspective, quantitative model-based scenario analyses are a valuable tool to assess energy systems transitions (Cherp et al. 2018; Grubler 2012). Importantly, however, the implications of a given scenario depend on the underlying assumptions and accuracy of the models. To avoid poorly designed energy policies, new research on the climate impact of methane (e.g. via leakage), non-business as usual assumptions and non-economic factors (Hoffart, Schmitt, and Roos 2021), should be included in scenarios. In many of the scenarios referred to by natural gas proponents, these aspects remain largely unexamined. A representative example is the scenario analysis study by Eurogas that only covers CO_2 from energy use and process emissions, while methane emissions are not covered at all (Warner ten Kate et al. 2020). Most importantly, the climate impacts of the use of natural gas have been systematically underestimated in energy system modelling and in the balance of national greenhouse gas inventories. This can be observed for example in the EU’s commonly used PRIMES energy system model (Höglund-Isaksson et al. 2016) and the linked GAINS model (applied e.g. in the EU Reference Scenario 2016 and 2020), which both use outdated GWP_{100} values. This is also the case e.g. in the German Environment Agency’s National Greenhouse Gas Inventory Reporting (German Environment Agency 2021).

The latest findings on fossil-fuel methane emissions need to be applied to modelling exercises, emissions-budget balancing of the energy system in climate protection scenarios, and climate policy derived from such models. Frequently, such calculations insufficiently account for methane emissions resulting from leakage during the production, transport and use of natural gas. They also often employ outdated (and therefore lower) values for global warming impact. Given that the world is quickly approaching several climate tipping points, accounting for short-term warming impacts (e.g. the 20-year time period) in addition to longer period warming (mostly calculated for 100 years) would be of great importance.

Energy system models might find that when incorporating full-life cycle GHG emissions and the updated warming potentials of methane, results on natural gas change drastically. It might force scientists to discard natural gas as anything besides a marginally used fuel, and consider other options, such as energy efficiency and sufficiency in degrowth scenarios (Keyßer and Lenzen 2021).

Even though this paper focuses on fossil natural gas, it should not be ignored that the development and expansion of a global hydrogen economy is also associated with climate-damaging emissions. On the one hand, the production of hydrogen from methane (steam reformation) leads to additional methane leakage from natural gas production while CO_2 continues to be emitted, because not all CO_2 from the reformation process is stored in a final repository (Bauer et al. 2021). Latest research on the climate impact of so called “blue-hydrogen” even showed, that burning “blue hydrogen” is related with 20% greater greenhouse gas footprint that burning the fossil natural gas itself (Howarth and Jacobson 2021). On the other hand, although not yet widely discussed, hydrogen leakage has also negative impact on the climate. Hydrogen, as a potent indirect greenhouse gas, increases the lifetime and amounts of other greenhouse gases such as methane, ozone and water resulting in additional warming effects in the atmosphere (Ocko and Hamburg 2022; Hormaza Mejia, Brouwer, and Mac Kinnon 2020). Given these circumstances, ambitions to limit leakage rates should focus on both, methane and hydrogen, especially when the goal is to plan climate-neutral 100%-renewable energy systems.

Research on the feasibility and transition pathways to 100%-renewable energy systems has grown significantly since the 2000s. Several publications for a variety of jurisdictions have shown that 100% renewables are technically feasible (Hansen, Breyer, and Lund 2019). A cross-sectoral perspective of the entire energy system, including fluctuating and dispatchable renewables, and various sources of flexibility (e.g. energy storage options, demand response, sector coupling) enable 100% renewable energy systems (Hansen, Breyer, and Lund 2019; Mathiesen et al. 2015). Nevertheless, the economic and political feasibility of the transition are still contested (Hoffart, Schmitt, and Roos 2021; Schubert, Thuß, and Möst 2015). This highlights the planning and governance challenges of restructuring global energy systems and in particular those with very high shares of renewables (Clack et al. 2017; Shaner et al. 2018; Denholm et al. 2021). While natural gas might help with the last few percent of energy provision to ease technical difficulties (Williams et al. 2021), it is important to acknowledge the required drastic reduction in absolute natural gas use. This reduction will most likely result in very low shares of capacity utilization of natural gas infrastructure (McGlade et al. 2018).

2.4 Misleading narratives prevent a direct shift to renewables

Agenda setting and the decision-making process at the political level do not take place in a purely objective and fact-based manner but are influenced e.g. by public discourse. In order for their own interests to be taken into account at the political level, actors feed them into discourses, for example in the form of narratives (Jones, Shanahan, and McBeth 2014). Narratives are easy to convey stories that, at the same time, offer a suitable solution proposal, which can influence the interpretation and understanding of an issue (Hermwille 2016, 238). How successfully a narrative sticks does not mainly depend on whether it is based on facts, but on whether it is coherent in and of itself and if it addresses the concerns of the audience in line with their core beliefs (Hermwille 2016).

Advocates of natural gas often use the “bridge technology” or “transition fuel” narratives to legitimize investments in natural gas infrastructure and natural gas usage in line with their own economic interests or beliefs.

The bridge technology narrative has been widely used since the 1970s in public discourses around energy transitions (Lovins 1976) (for examples see (Wilson, C L. 1980; Delborne et al. 2020)). Besides framing the current dominant energy technology (mix) as the problem, this narrative also claims that renewable energy technologies are too technologically immature or unreliable to replace fossil fuels. The solution the narrative presents is that gas is a “bridge technology” that, while having its own drawbacks, is still better than the old technology and will help to buy time until renewable energy technologies are mature enough. The “bridge” narrative seems coherent as long as it is convincing that the “bridge technology” offers sufficient advantages over the old technology to make the necessary additional investments viable. It is easy for several diverse actors to agree on the “bridge technology” narrative. This unifying effect is possible because the narrative remains imprecise at crucial points: For example, no information is given about what system the “bridge” leads to, or until which year the “bridge” should last (Delborne et al. 2020).

When the “bridge technology” narrative became popular in the public discourse, coal (“ready” for carbon capture, transport and storage) was considered to be the bridge (Wilson, C L. 1980). This shifted, especially since the shale gas revolution in 2008, and natural gas became the new “bridge” technology. The long coal “bridge” since the 1970s, and the ease with which the “bridge technology” narrative has moved from coal to gas, suggests that the narrative mainly serves to legitimise the continued use of fossil fuels, instead of accelerating the transition to renewables (Delborne et al. 2020; von Hirschhausen, Kemfert, and Praeger 2021). Now, fossil natural gas is often presented as a necessary intermediate step for sustainable system transformations (Safari et al. 2019), and as an enabler of a hydrogen economy (Dickel 2020; Sánchez-Bastardo, Schlögl, and Ruland 2021).

2.5 Natural gas lock-ins delay renewable energy transitions

Another argument that proponents of natural gas use is that it is needed to meet national and international climate targets because of its low emissions. This argument is misleading because natural gas causes more emissions than often attributed to it (see above). Furthermore, the ongoing use of natural gas creates carbon lock-ins, which could likely delay the energy transition to renewables (Gürsan and de Gooyert 2021). The term “carbon lock-in” describes the interaction of fossil fuel-based technological systems and related institutions that create barriers to the phase-out of fossil fuels (Unruh 2000), and thus hinder the use of renewable technologies. Carbon lock-in mechanisms can for instance be of an infrastructural, institutional or behavioural nature (Seto et al. 2016).

As gas pipelines, LNG terminals and gas-fired power plants have a technical lifetime of several decades, they pose a particularly great risk for carbon lock-ins. Tong et al. (2019) noted that if the currently existing energy infrastructure continues to operate as it has historically, approximately 658 Gt CO_2 will be released. These emissions would already exceed the entire remaining carbon budget to limit global warming to 1.5°C (420–580 Gt CO_2). From a climate target perspective, this means that the operation time of infrastructure must be curtailed. However, the global use of natural gas is still growing significantly (Peters et al. 2020), which will require even lower utilisation rates, or earlier decommissioning of existing infrastructure. Due to institutional lock-in mechanisms, such as the legal protection of property and opposition from asset owners, the decommissioning of privately owned infrastructure after only a fraction of its lifespan is very challenging (Serkin and Vandenbergh 2018).

To circumvent the redundancy of natural gas infrastructure or even to justify the construction of new infrastructure, incumbent actors, particularly in Europe, have proposed the use of synthetic gases and e-fuels in all sectors (van Renssen 2020). Regardless of whether a repurposing of the infrastructure is at all technically possible or economically viable, this idea poses a danger of carbon lock-in. If, as for example envisaged in the EU hydrogen strategy (EC 2020a) synthetic gases are first produced by steam methane reforming (SMR) with carbon capture, transport and storage facilities, it will be necessary to construct comprehensive new infrastructure. This would create additional potential for infrastructural and technological carbon lock-in. Hydrogen production from SMR, and thus of all its derivatives, still causes methane emissions from upstream and midstream natural gas value chains (Howarth and Jacobson 2021; Global Witness 2022), and SMR itself emits a significant amount of greenhouse gases (Sun et al. 2019). Today, SMR (without carbon capture, transport and storage) is responsible for around three quarters of global hydrogen production (IEA 2019c); an expansion of this process would lead to a significant increase in emissions compared to the direct use of natural gas (Howarth and Jacobson 2021). Besides that, there is a risk that the production of renewable synthetic gases would not be sufficient to replace fossil fuel-based gases and fuels in the medium to long term (Ueckerdt et al. 2021).

2.6 Investments in gas infrastructure imply economic risks

It is often argued that investments in natural gas are preferable to those in renewable energy technologies, which are supposedly still technologically immature and comparatively expensive. This argument is misleading, as investments in natural gas infrastructure pose serious economic risks.

One major economic risk is energy asset stranding, resulting in a key challenge of the transition to renewable energy sources (Löffler et al. 2019). Stranded assets are “assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities” (Caldecott et al. 2016). The risk of asset stranding applies to existing and new natural gas infrastructure, due to their long technical lifespans and amortisation periods. Smith et al. (2019) show that the use of existing and planned fossil-fuel infrastructure is not compatible with the 1.5°C target and that investments in new fossil-fuel infrastructure are highly risky. Due to the diffusion of low-emission technologies and stricter climate policy, the demand for fossil fuels will decline (Mercure et al. 2018). Hence, the operation of the new infrastructure needs to end before their technical lifetime, causing massive financial losses (Sen and von Schickfus 2020).

The financial sector (ECB 2020; BaFin 2020), academics (Monasterolo et al. 2017), governments (Loew et al. 2021), and non-governmental organisations[26] have warned about the carbon bubble and cited stranded assets as a key climate-related financial risk. These risks are so-called “sustainability risks”

[26] Carbon Tracker Initiative. 2011. “Unburnable Carbon: Are the World’s Financial Markets Carrying a Carbon Bubble?” Accessed February 18, 2023. https://carbontracker.org/reports/carbon-bubble.

and result from the physical impact of climate change (physical risks) as well as changes in climate policy accompanying the net-zero transition (transition risk) (Batten, Sowerbutts, and Tanaka 2016).

Although estimates on global gas infrastructure stranding are not yet available to our knowledge, calculations for fossil-fuel assets and the gas sector provide some insights. According to Mercure et al., global fossil-fuel assets might cause a discounted loss in global wealth of USD 7–11 trillion (Mercure et al. 2021). Current gas and oil projects worth at least USD 2.3 trillion are not aligned with the Paris Agreement.[27] (Carbon Tracker Initiative 2017). In 2030, up to USD 90 billion of today's coal and gas power plants could become stranded (with USD 400 billion of stranded assets by 2050) (IEA 2021b).

Besides the lack of research on gas infrastructure stranding, the economic losses from stranded gas assets are a source of great uncertainty and could thus be much higher. This uncertainty is due to immature calculation approaches of asset stranding (Ansari and Holz 2020), the timing of climate policies (van der Ploeg and Rezai 2020), and the expectations of investors (Mercure et al. 2018). Confidence in the continuation of fossil-fuel consumption is still high (Mercure et al. 2018). Consequently, investors rarely adjust their investment behaviour, as they expect compensation in case of losses (Sen and von Schickfus 2020). Ignoring the risk of asset stranding and further investments in fossil-fuel infrastructure will amplify the economic risks (Löffler et al. 2019).

Methane leakage regulations might be a cause for additional stranded assets. In particular, the Global Methane Pledge launched at COP26 has the potential to create a new momentum on regulating methane leakages. As the industry hardly addressed leakages since at least the 1990s (D. Wilson 1990; Tie and Mroz 1993), it is crucial to leave the related duties not solely to the industry. However, attempts to minimize leakages via regulation have proven difficult too (Dobson, Goodday, and Winter 2021). Since these regulations and leakage controls can never replace a strong reduction in natural gas consumption, leakage control technologies might also strand in the long run.

The underestimation of climate-related asset stranding (Caldecott and McDaniels 2014) has two main implications. First, it leads to a misallocation of capital towards emission-intensive technologies (IRENA and IEA/OECD 2017). In other words, investment in natural gas infrastructure locks up capital, which is then no longer available for investments in renewable energies, in turn delaying the energy transition (Davis and Shearer 2014). In the light of the green energy financing gap, large investments are necessary to enable an energy system transformation (Yoshino, Taghizadeh–Hesary, and Nakahigashi 2019). Second, widespread climate related asset stranding could cause a cascading effect on coupled sectors, in particular the financial sector (Campiglio, Godin, and Kemp-Benedict 2017). If, therefore, financial institutions were struggling to provide credits, this would also restrict possibilities to make necessary investments in the renewable energy transition. Fossil divestment might be a powerful measure for international authorities and financial institutions to reduce climate-related financial risk and to avoid delaying energy transitions.

[27] Carbon Tracker Initiative. 2017. "2 Degrees of Separation – Transition Risk for Oil and Gas in a Low Carbon World." Accessed February 18, 2023. https://carbontracker.org/reports/2-degrees-of-separation-transition-risk-for-oil-and-gas-in-a-low-carbon-world-2/.

2.7 Outlook

In summary, a fossil fuel with a high climate impact, often hidden under a misleading narrative, which hinders decarbonisation via infrastructure expansion creating carbon lock-in effects and bears high economic risk, cannot be a solution towards a zero-emission future.

The potentially detrimental impacts of fossil natural gas call for research on how to achieve a 100% renewable energy supply while strictly minimizing natural gas use during the transitional period. Based on the five different perspectives discussed herein, we propose five recommendations for further stimulating the debate on the risks related to natural gas use.

First, the management of GHG emissions, especially methane leakage along the entire natural gas value chain, requires significant improvement. Taking a climate science perspective, the latest research on methane emissions from natural gas infrastructure shows a higher climate impact than was previously assumed. This means that countries attempting to develop decarbonisation strategies need to carefully assess whether natural gas can play a role in them. To do so, it is crucial to improve the measurement, accounting and reduction of GHG emissions along the value chain (this requires accurate and transparent GHG inventories), especially to minimize methane leakage. Eventually, as regulation cannot reduce methane emissions to zero and natural gas causes significant CO_2 emissions when it is burned, an end of natural gas use is needed.

Second, to avoid misleading policies, the assumptions of scenario analyses need to be revised to include new research insights on GHG emissions related to natural gas. From a methodological perspective, scenario analyses need to incorporate the latest findings on methane emissions resulting along the whole chain of natural gas production and use. Doing so reveals the much smaller role that natural gas can play in global energy systems and highlights the importance of planning the phase-out of natural gas. Consequently, such scenario analyses would also demonstrate the increasing importance of immediate investment in energy efficiency measures and the massive expansion of renewable energy sources.

Third, narratives presenting gas as climate friendly need to be replaced with unambiguous criteria. From a discursive perspective, the bridge technology or transition fuel narratives lack clarity regarding aspects such as the time horizon and the target system, and are utilized to legitimise natural gas use. Clearer concepts are needed, with unambiguous criteria and limits for GHG emissions from energy production in various years and for various applications, accompanied by a narrative based on a 100%-renewable energy system.

Fourth, to meet climate targets, further lock-ins must be avoided. Additional expansions of natural gas infrastructure and consumption aggravate infrastructural and institutional lock-in effects, which slow down the transition to renewable energy systems. To effectively govern the transition, these lock-in effects need to be taken into account in energy infrastructure planning, even and especially if the expansion is legitimised with plans to replace natural gas with synthetic gases or e-fuels in the long term.

Finally, climate-related risks such as asset stranding need to be taken seriously in energy infrastructure planning. From an economic perspective, investments in additional natural gas energy infrastructure are a poor fit for climate targets and would cause massive economic losses from asset stranding. Additionally, they can delay needed investments in a renewable energy-based system. Consequently, investment decisions by the private sector and state actors need to take climate-related risk from asset stranding seriously.

The five different perspectives and related recommendations demonstrate the need for a more holistic assessment of all GHG emissions related to natural gas and infrastructure expansion, as well as its impact on energy transitions. Political and scientific debates should focus more on how to reduce the production and use of natural gas to accelerate the shift towards renewable energy systems. Meeting the Paris Agreement and longer-term climate mitigation targets inevitably implies a fossil natural gas exit. The earlier such a gas exit is planned for, the more of the emission budget remains for those sectors which are harder to decarbonize.

3 Chapter 3: Liquefied natural gas expansion plans in Germany: The risk of gas lock-in under energy transitions

3.1 Introduction

Natural gas use is the most rapidly growing among all fossil fuels, and was responsible for about 35% of growth in global CO_2 emissions since 2009 (Peters et al. 2020, 5).[28] While some present natural gas as a 'bridge technology' (Neumann and Hirschhausen 2015; Ausubel, Grubler, and Nakicenovic 1988),[29] others argue that this is an ambiguous narrative to influence expectations and visions regarding natural gas (Delborne et al. 2020). In fact, using natural gas as a substitute for coal can lead to negative climate consequences due to so far underestimated life cycle emissions (Howarth 2014; 2019; Alvarez et al. 2018; Cremonese and Gusev 2016) and a delay of a climate neutral energy system (Zhang et al. 2016). Here, we highlight a third risk of natural gas as a bridge fuel: locking-in large-scale carbon-intensive infrastructure, which could undermine long-term climate goals.

The current rise in natural gas use is also reflected in the dawn of new infrastructure for trading Liquefied Natural Gas (LNG): Global LNG export infrastructure grew to 442 million tons per annum (MTPA) in May 2020, and LNG import infrastructure currently stands at 844 MTPA (Plante et al. 2020).[30] This compares to an LNG trade of 355 MT in 2019 (GIIGNL 2019), an increase of ~45% compared to 2015.[31, 32] The existing oversupply on the global market – especially due to new supplies from Australia, the United States and Russia – has led suppliers to search for new export possibilities, and Europe is becoming an attractive import market for LNG, as today's low LNG prices converge to the continent's pipeline prices.

We thus examine the growing tension between the expansion of LNG infrastructure and climate protection goals. We use Germany as an ideal case to examine this tension because the country is widely recognised as a climate leader with impressive progress in its energy transition and ambitious decarbonisation plans while at the same time offering strong state support to three new LNG terminals (Table 3). We also believe that Germany is a particularly instructive case for a challenge, which other states may face as they enter the 'next phase' of the energy transition – when renewables reach a larger share of the electricity sector and the decline of existing technologies begins (Markard 2018). Like many

[28] This chapter is published as Brauers et al. (2021) in *Energy Research & Social Sciences* 76. Joint work with Hanna Brauers and Jessica Jewell. The conceptualisation, methodology investigation, interviews, and formal analysis were conducted jointly with Hanna Brauers. The manuscript was written jointly with Hanna Brauers and Jessica Jewell.

[29] They mostly base this assumption on the fact that natural gas can emit up to 60% less CO_2 emissions compared to coal, when one accounts only for the burning process (Hausfather 2015). However, when accounting for life cycle emissions the outcome is less positive (Alvarez et al. 2012).

[30] Another 122 MTPA of export capacities and 144 MTPA of import capacities are currently under construction (Plante et al. 2020).

[31] Statista Research Department. 2020. "Liquefied Natural Gas Trade Volume Worldwide from 1970 to 2019 (in Billion Cubic Meters)." Accessed September 28, 2020. https://www.statista.com/statistics/264000/global-lng-trade-volume-since-1970/.

[32] Shipping natural gas as LNG additionally increases the greenhouse gas footprint, due to cooling and pressurising.

other states, Germany has pledged to phase-out coal[33], and additionally nuclear energy, but the pathway of the remaining energy transition to reach its emission reductions target is still unclear.

In our paper, we answer the following research questions: How do the material conditions around natural gas consumption and LNG infrastructure relate to and interact with actors' perceptions of these conditions? And how do these interactions shape systemic changes and create lock-ins for the German energy transition?

We do this by analysing the co-evolution of key energy technologies and markets, the related socio-technical system and the political system, and analyse how actors' perceptions shape and are shaped by each of these realms. Our methodological innovation is the further development of a meta-theoretical framework on energy transitions (Cherp et al. 2018) (see Section 3.4). More specifically, we use the meta-theoretical framework (Cherp et al. 2018) as a map to identify relevant questions and actors to probe through a series of interviews and workshops.

As a result, we are able to identify the role of structural developments regarding the energy market as well as the role of actors and their interests and perceptions in the respective decision-making process. We show that (A) support for the planned LNG terminals in Germany arises from geopolitical influence from the US, combined with (B) concerns over security of supply mainly due to the coal phase-out and reliance on Russian natural gas imports, (C) pressure from a wide variety of actors benefiting from high levels of natural gas consumption, (D) sunk investments in existing gas infrastructure, (E) the support of the arising synthetic gas niche, as well as (F) a weak opposition against LNG and natural gas in general. These findings are particularly relevant for other EU countries phasing-out coal, which may face similar concerns and pressure and may also consider natural gas as a bridge fuel within the energy transition.

3.2 Case description

Figure 5 depicts all existing and planned LNG terminals in the EU. As of January 2021, there were three potential locations for large-scale LNG terminals in Germany.[34] All locations are in the North of the country: Brunsbüttel in the state of Schleswig-Holstein, and Wilhelmshaven and Stade in Lower Saxony. Together the three terminals would account for ~30 billion cubic meters (bcm) of natural gas (Table 3). Jointly, they represent the case of LNG in Germany, which we analyse in this paper.

[33] Clean Energy Wire. 2020. "Spelling out the coal exit – Germany's phase-out plan." Accessed September 28, 2020. https://t1p.de/lq0v.

[34] One additional small-scale terminal has been proposed in Rostock (also in a Northern state of Germany - Mecklenburg-Western Pomerania). As the Rostock terminal is much smaller in scale than the other three terminals, and it would not become connected to the gas grid in case of construction, we exclude it from the further analysis.

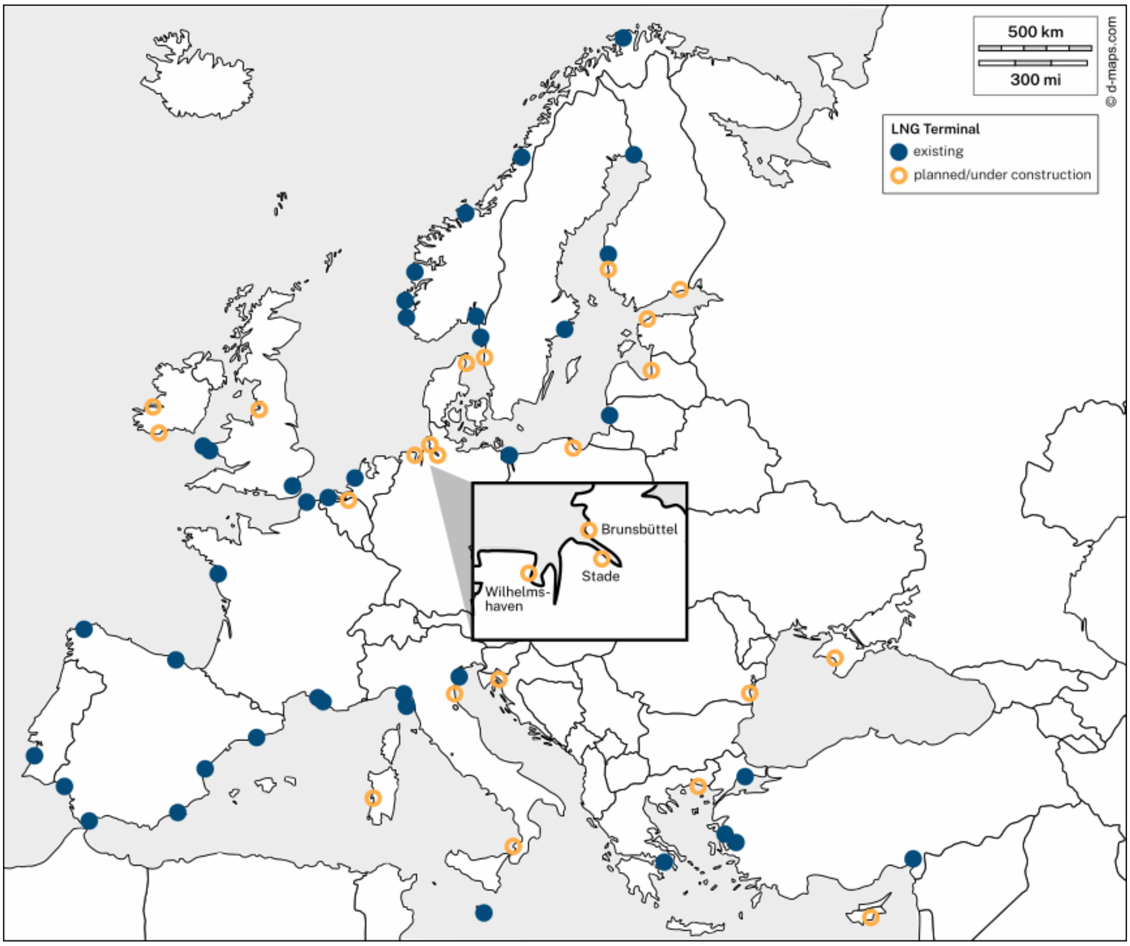

Figure 5: Existing and planned LNG terminals in Germany and the EU.

Source: Authors' illustration based on d-maps and the Global Energy Monitor.[35]

None of the projects have a final investment decision or construction permit. Proposals for the terminal in Wilhelmshaven have been made and withdrawn repeatedly since the 1970s. The approval for a land-based terminal was granted in 2007. However, the plan changed to build a Floating Storage Regasification Unit (FSRU), for which no approval exists (as of February 2021). The consortium to build the Brunsbüttel terminal – German LNG Terminal – was founded in 2018, and the terminal in Stade was announced the same year. All of the terminals are supposed to be connected to the existing natural gas grid, which requires the construction of connecting pipelines, resulting in further major investment costs (see Table 3 and Section 3.6).

Schleswig-Holstein's and Lower Saxony's licencing authorities decide on the permits for the respective terminals. Those scoping, regional planning as well as zoning procedures[36] – including e.g. the environmental impact assessment – typically take several years from the initial proposal to the approval,

[35] d-maps. 2021. "Map Europe" Accessed September 19, 2021. https://d-maps.com/carte.php?num_car=2233&lang=en. Global Energy Monitor. 2021 "Europe Gas Tracker" Accessed September 19, 2021. https://globalenergymonitor.org/projects/europe-gas-tracker/tracker-map/.

[36] In German „Raumordnungsverfahren“ and „Planfeststellungsverfahren“.

procedural handling, construction, and commissioning. The responsible agencies differ depending on the federal states and are subordinate to different federal state ministries.[37] In the official approval processes, anyone can submit a position statement, voicing support or criticism. The respective offices of the state governments are also subject to lobbying efforts, making the political level as important as the planning and economic level.

Approval needs to be granted both for the terminals themselves and the respective connecting pipelines. Generally, the agencies responsible for the approval processes are only dependent on the existing law. However, included information in the processes depend also on the position of the federal state governments and the respective ministries, where especially Lower Saxony is very supportive of LNG, founding its own LNG agency.[38]

Responsible for the financing of the terminals are the respective private companies. However, the respective state governments of Lower Saxony and Schleswig-Holstein actively support the projects by including them in their coalition agreements[39] and by providing funding, in addition to support by the national government. The Joint Task for the Improvement of Regional Economic Structures (GRW) promised funds for the Brunsbüttel and Wilhelmshaven sites. The state of Schleswig-Holstein had already earmarked €50 million for the Brunsbüttel LNG terminal in its 2020 budget. As these are GRW funds[40], the federal government would match the €50 million budget, as part of complementary financing, in the event of a final allocation. In addition, funding opportunities for alternative fuel infrastructure exist as part of the national mobility and fuel strategy, and according to the national government, construction cost subsidies for the development of an LNG port infrastructure are to be provided as well. Lastly, a letter from finance minister Scholz in August 2020 promised €1 billion in German subsidies for the Wilhelmshaven and Brunsbüttel terminals, if the US would "allow for the unhindered construction and operation of Nord Stream 2".[41]

Nevertheless, the investment decisions of the LNG project companies have been delayed for some time. In November 2020, Uniper announced that it would review its plans to build an LNG terminal in Wilhelmshaven, after not receiving enough binding capacity bookings from market participants in the pre-tender process. German LNG Terminal, the investor for the terminal in Brunsbüttel, already had to

[37] See e.g. Schleswig Holstein Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus. 2019. "German LNG-Terminal in Brunsbüttel. Unterrichtung gemäß § 15 UVPG über den Untersuchungsrahmen." Accessed September 19, 2021. https://t1p.de/xmdg. Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus Amt für Planfeststellung Verkehr. 2020. "German LNG-Terminal Brunsbüttel – Beginn Planfeststellungsverfahren. Accessed September 19, 2021. https://t1p.de/o3ks. Landesbüro Naturschutz Niedersachsen GbR. 2021. "Beteiligung in Umweltfragen". Accessed September 19, 2021. https://umwelt-beteiligung-niedersachsen.de/faq-page#n16; LabüN Gbr. 2019. "Ergänzende Stellungnahme zum Scoping-Termin zum Vorhaben der Uniper Global Commodities SE für ein LNG FSRU Import Terminal Wilhelmshaven". Accessed September 19, 2021. https://t1p.de/h1gk.

[38] LNG Agentur Niedersachsen. 2020. "LNG-Entwicklung an der niedersächsischen Nordsee." Accessed September 19, 2021. https://t1p.de/jszx.

[39] Coalition agreements from 2017 in Lower-Saxony https://t1p.de/9xex and Schleswig-Holstein https://t1p.de/4202. Accessed September 19, 2021.

[40] For an explanation of this concept of Regional Development Policy in Germany see OECD. 2019 "Regional Development Policy in Germany." Accessed September 19, 2021. https://www.oecd.org/cfe/_Germany.pdf.

[41] Federal Ministry of Finance, Non Paper Germany Nord Stream 2/U.S. LNG (2020). Accessed September 19, 2021. https://t1p.de/s7cq.

ask for an extension until June 2022 for the final investment decision. The project in Stade plans to take the investment decision in 2021 and to commission the LNG terminal by 2026.

	Wilhelmshaven Lower Saxony	**Brunsbüttel** Schleswig-Holstein	**Stade** Lower Saxony
Operators/ Investors	uniper; MOL Mitsui O.S.K. Lines	German LNG Terminal; gasunie; Vopak; Oiltanking	DOW; Hanseatic Energy Hub; HEC 中国港湾工程有限责任公司; MACQUARIE
Storage capacity	263,000 cm	480,000 cm	480,000 cm
Annual capacity	10 bcm (incl. FSRU)	8 bcm	4-12 bcm
Connection to grid	Yes	Yes	Yes
Investment costs	~ €1.5 billion (shore-side terminal) ~ €130 million (FSRU)	~€500 million	~€850 million
Construction/ operating costs of connecting pipeline	~ €86 million for connecting pipeline and ~ €690,000 for annual operating costs	~ €87 million for connecting pipeline and ~ €700,000 for annual operating costs	~ €31 million for connecting pipeline and ~ €245,000 for annual operating costs
Status (January 2021)	• No permit for construction for FSRU • No final investment decision (FID)	• No permit for construction • No FID	• No permit for construction • No FID

Table 3: Short profile of planned large-scale import LNG terminals in Germany.

Sources: Own depiction based on (Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr 2015; Deutscher Bundestag 2020; Bundesrat 2019).[42]

Note: An FSRU is a Floating Storage Regasification Unit.

[42] And the follwing sources: Czechanowski, Thorsten. 2019. "LNG-Terminal Wilhelmshaven sucht Interessenten." Accessed May 20, 2019. https://www.energate-messenger.de/news/191830/lng-terminal-wilhelmshaven-sucht-interessenten; Dammann, Jörg. 2018. "LNG: Vieles spricht für Stade." Accessed November 9, 2018. https://www.kreiszeitung-wochenblatt.de/stade/c-politik/lng-vieles-spricht-fuer-stade_a126581; German LNG Terminal. 2018. "Geplante Ausstattung des Terminals." German LNG Terminal. Accessed May 20, 2019. https://germanlng.com/de/geplante-ausstattung-des-terminals/; Handelsblatt. 2018. "Offenes Rennen um Deutschlands erstes Flüssiggas-Terminal." Acessed September 18, 2018. https://www.handelsblatt.com/politik/deutschland/gasnetz-offenes-rennen-um-deutschlands-erstes-fluessiggas-terminal/23079402.html?ticket=ST-955168-ypkb1KbuV3IWGekPSXy0-ap4; LNG.Agentur. 2020. "LNG-Entwicklung an der niedersächsischen Nordsee." Acessed September 18, 2018. https://lng-agentur.de/lng-development-on-the-north-sea-coast-of-lower-saxony/; Maksimenko, Artjom. 2018. "Stade will LNG-Standort werden." Accessed May 30, 2018. https://www.energate-messenger.de/news/183461/stade-will-lng-standort-werden; NDR1 Niedersachsen. 2018. "Rennen um LNG-Terminal geht auf die Zielgerade." Accessed September 18, 2018. https://www.ndr.de/nachrichten/niedersachsen/lueneburg_heide_unterelbe/Rennen-um-LNG-Terminal-geht-auf-die-Zielgerade,lng128.html; NDR1 Niedersachsen. 2018. "Erdgas-Terminal: Stade denkt schon an Baustart." Accessed November 9, 2018. https://www.ndr.de/nachrichten/niedersachsen/lueneburg_heide_unterelbe/Erdgas-Terminal-Stade-denkt-schon-an-Baustart,lng142.html; Oiltanking. 2019. "Axpo und German LNG Terminal vereinbaren Heads of Agreement über einen Kapazitätsvertrag." Accessed November 9, 2018. https://www.oiltanking.com/de/news-info/pressemitteilungen/details/article/axpo-und-german-lng-terminal-vereinbaren-heads-of-agreement-ueber-einen-kapazitaetsvertrag.html; RWE Supply & Trading GmbH. 2018. "RWE und German LNG Terminal vereinbaren Kapazitätsvertrag für erstes deutsches LNG-Terminal." Accessed September 6, 2018. https://news.rwe.com/rwe-und-german-lng-terminal-vereinbaren-kapazitatsvertrag-fur-erstes-deutsches-lng-terminal; Stratmann, Klaus. 2019. "Gasversorgung: LNG-Terminal in Sicht – Bewerber Brunsbüttel findet neuen Kunden." Accessed February 11, 2019. https://www.handelsblatt.com/politik/deutschland/gasversorgung-lng-terminal-in-sicht-bewerber-brunsbuettel-findet-neuen-kunden/23973108.html; Süddeutsche Zeitung. 2019. "Premiere: Flüssigerdgas von

The LNG terminal in Wilhelmshaven is meant to create around ~50-60 long-term jobs.[43] The terminal in Brunsbüttel is expected to create ~70 long-term employees directly by the terminal, and ~1,000 for the construction time of around three years.[44] More generally, in Brunsbüttel the operators of the terminals suggest that the local constituencies can expect a durable increase in employment, regional value added and taxes.[45]

3.3 Theoretical approach

Here, we consider LNG terminals as part of the energy transition in Germany. Energy transitions are long-term structural changes of energy systems (Grubler 2012), which evolve along specific pathways (Rosenbloom 2017). As such, they exhibit path-dependence, or inertia to large-scale change. The entrenchment of existing systems, which underpin the fossil-fuel intensive energy system, is commonly referred to as 'carbon lock-in' (Seto et al. 2016). Unpacking the connection between lock-in and the energy transition is key to understanding what has been called the 'next phase of the energy transition' (Markard 2018): This next phase begins when the growth of new technologies accelerates to an extent that challenges established technologies, business models, practices and actors. Here, the key question is no longer concerned with understanding the emergence of new technologies but understanding the inertia of a system – a lock-in.

In order to disentangle this connection, we follow a meta-theoretical framework (2018; 2017), which conceptualises energy transitions as unfolding in three autonomous but co-evolving systems: a) policy system (composed of political actions and policies), b) techno-economic system (composed of energy flows and markets), and c) socio-technical system (composed of energy technologies and artefacts, businesses and practices).[46] The development and interaction of each of the three systems – or realms as we refer to them as of now in this paper – can explain the course of energy transitions. With reference to Elinor Ostrom's research (Ostrom 2005), all three realms are described as semi-autonomous with e.g. their own elements, boundaries and dynamics. While all three realms can develop independently of each other, they also interact, and hence co-evolve. The framework makes it possible to identify mechanisms affecting one or several of the three realms, explaining course of change – or lock-in. These

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Schiff zu Schiff getankt." Accessed July 13, 2020. https://www.sueddeutsche.de/wirtschaft/schifffahrt-brunsbuettel-premiere-fluessigerdgas-von-schiff-zu-schiff-getankt-dpa.urn-newsml-dpa-com-20090101-191004-99-159422; Boyens Medien. 2019. "Boyens Medien: LNG-Terminal: Investoren Beantragen Genehmigung." Accessed July 13, 2020. https://www.boyens-medien.de/artikel/dithmarschen/lng-terminal-investoren-beantragen-genehmigung.html.

[43] GRÜNE Wilhelmshaven, Positionspapier zum LNG-Terminal in Wilhelmshaven (2021). https://t1p.de/rz45.

[44] CPL Competence in Ports and Logistics GmbH, Regionalökonomische Effekte eines LNG-Terminals (2019). https://t1p.de/kd17. For Stade, no explicit numbers of expected jobs were available to us.

[45] Ibid.

[46] Various other frameworks have been developed within the transition research community to explain energy transitions and to identify relevant variables, most prominently (Markard, Raven, and Truffer 2012; Fuenfschilling and Truffer 2014): transition management (Loorbach 2010), strategic niche management (Kemp, Schot, and Hoogma 1998), the multi-level perspective (F. W. Geels 2002), and technological innovation systems (Bo Carlsson et al. 2002). Rooted in evolutionary economics and Science and Technology Studies (STS), all these frameworks share the concepts of a socio-technical system, a socio-technical regime as well as a niche and thus primarily can explain the development of the socio-technical system. In contrast, the approach we use here (Cherp et al. 2018) can account for important political economy aspects shaping energy transitions, such as how techno-economic developments shape and constrain choices, and how the policy system co-evolves with the socio-technical system.

dynamics are shaped by both *material realities* and *actor perceptions* (Cherp et al. 2018),[47] with lock-in playing a distinct role in each of these realms.

We consider all three co-evolving realms and their developments as well as the international context to explain the political support for the construction of LNG terminals in Germany and explore whether this fosters lock-in during the next phase of the energy transition (see Table 4):

a) Political realm: The political realm covers how policies shape the energy system and how special interests shape policies (Cherp et al. 2017). Thus, the focus is on policy systems – encompassing political actions and energy policies. Most relevant to the next phase of the energy transition is how the state, as an actor, navigates the supply-demand balance (Helm 2002), particularly in the face of growing variable renewable sources. Also of interest is how different interests are mediated by political processes and institutions (Aklin and Urpelainen 2013; Dumas, Rising, and Urpelainen 2016). We understand institutions as formal and informal structures, which shape society (e.g. policies, standards, rules, values) (Fuenfschilling and Truffer 2014).

Thus, the political realm is characterised by what Seto et al. (2016) refer to as *institutional lock-in*, whereby various interests and actors benefit from the status quo. Institutional lock-in exists as institutions strongly discourage and impede change once they are established, and institutions get defended by (a powerful network of) beneficiaries (Thelen 1999). To what extent policy-makers are able to break the lock-in may be to a large extent mediated by the state's overall capacity to balance diffuse with concentrated interests (Inchauste and Victor 2017; Jewell et al. 2019). The agency of actors can determine the direction and extent of institutional change (Becker, Beveridge, and Röhring 2016). Additionally, we include *discursive lock-in* in our analysis of the political realm: "A discourse assigns meaning, defines power relations and creates subjects and objects through practices. A discourse is always in competition with other discourses and is struggling for its reproduction (by practices) and for dominance in a field" (Buschmann and Oels 2019, 2). Therefore, dominant discourses in the political realm can constitute and justify technologies, institutions and behaviours (Buschmann and Oels 2019), and deserve particular attention in understanding energy transitions (see also (Hajer 1995; Foucault 1966)). Here, the discursive debate with regards to gas (von Hirschhausen, Praeger, and Kemfert 2020) is mainly about whether it perpetuates carbon lock-in or creates a bridge to low-carbon sources.

b) Techno-economic realm: The techno-economic realm covers energy flows and markets (Cherp et al. 2018). Most relevant to the next phase of the energy transition is how to manage base load demand and how to transition a larger portion of the energy system to low-carbon, mostly variable electricity sources. Here, the focus is on the infrastructure itself and quantifying the value investors lose under different climate policies (Wake 2020). Stranded assets – either unpaid capital costs or lost profits due to climate policies – is thus a concept closely related to lock-in, known in the framework of Seto et al. (Seto et al. 2016) as *infrastructural and technological lock-in*. The theory is that the investment in a given infrastructure leads to increased inertia and lock-in to preserve the profits from that infrastructure

[47] By material realities we mean the concrete challenges and constraints energy policies face, such as meeting rising energy demand with secure supply (Helm 2002), technology availability as well as existing regulations, whereas by perceptions we mean how these realities are seen.

(Bertram et al. 2015; Caldecott and McDaniels 2014; Johnson et al. 2015). The infrastructure lock-in consists of a lock-in directly by existing infrastructure emitting GHGs (e.g. power plants), supporting infrastructure (such as pipelines or LNG terminals), and built infrastructure of human societies (e.g. gas heating in homes) (Buschmann and Oels 2019; Pierson 2000; Arthur 1994; Hanmer and Abram 2017).

c) Socio-technical realm: The socio-technical realm covers the emergence and diffusion of new technologies as well as their struggle with existing ones. In the socio-technical realm, the systemic focus is on energy technologies, artefacts, businesses and practices embedded in socio-technical systems. Most relevant to the next phase of the energy transition using socio-technical transition analysis (F. W. Geels et al. 2016; Turnheim et al. 2015; F. W. Geels, Berkhout, and Vuuren 2016) is to understand regime resilience (F. W. Geels 2002; Rip and Kemp 1998), particularly amidst growing pressure from new(ish) entrants. This connects to what Seto et al. (Seto et al. 2016) call *behavioural lock-in,* which is the continuation of current practices through individual decisions and choices, influenced also by social norms and cultural values. However, behavioural lock-in is a much less mature scientific concept than institutional lock-in or infrastructure lock-in (Fisch-Romito et al. 2021). Behavioural lock-in could be gauged by the technology-specific strength and pervasiveness of consumer habits (Erickson et al. 2015).

One form of a lock-in in the socio-technical realm has previously been termed *regime resistance* (F. W. Geels 2014). Regime resistance combines instrumental, discursive, material and institutional forms of power. Instrumental forms of power thereby refer to strategies of actors using their resources and cooperation with others to fulfil their interests. Discursive strategies aim to shape which and how issues are publicly and politically discussed. Material strategies target the technical dimension and focus especially on technical capabilities and financial resources, e.g. to attract further funding or to prevent regulation. The broader institutional power of actors is embedded in political cultures, ideology and governance structures, and this context can support regime resistance (F. W. Geels 2014). The deployment of such structural power depends on how interests and ideas are promoted and used and how they rely on institutional opportunities (Lockwood, Mitchell, and Hoggett 2019).

Realm	**Systemic focus (based on** (Cherp et al. 2018)**)**	**Key concepts for the next phase of the energy transition**	**The role of lock-in in this realm (developed from** (Seto et al. 2016)**)**
Political realm	Policy systems – political actions and energy policies	State balancing supply and demand and competing interests	Institutional lock-in, particularly vested interests, and discursive lock-in, particularly from incumbents
Techno-economic realm	Energy flows and markets	Managing stable energy provision and transition of a larger portion of the energy system to low-carbon	Infrastructural and technological lock-in, particularly stranded assets
Socio-technical realm	Energy technologies and artefacts, businesses and practices embedded in socio-technical systems	Understanding regime resilience particularly amidst increased pressure from new(ish) entrants	Behavioural lock-in, or the continuation of suboptimal technology use, regime resistance in the form of combined instrumental, discursive, material and institutional forms of power

Table 4: Systemic focus, key concepts and role of lock-in in each realm.

One key theoretical question is how these relatively autonomous realms interact. Policies, artefacts and actors all connect and influence the three realms (grey boxes in Figure 6). A policy, such as a feed-in-tariff, is born out of a given political climate in the political realm, changes the profitability of different generation sources in the energy realm, and empowers a niche in the socio-technical realm. An artefact, such as a new technology can make certain pathways possible in the techno-economic realm but may also destabilise a regime in the socio-technical realm. Here, we focus on how key actors walk across realms, play different roles in different realms and thus facilitate their co-evolution. This has important implications because it is actors who have agency and can shape the unfolding energy transition and have the capacity to slow it down or speed it up (Kern and Rogge 2016).

Actors have different abilities to “mobilize resources to achieve a certain goal” (Avelino and Rotmans 2009, 550). Resources can be e.g. human capacity, and mental or capital assets. To achieve their goals, actors need – besides access to resources – strategies to mobilise and skills to apply them, as well as the willingness to do so (Avelino and Rotmans 2009). The more resources an actor has, and the better the strategies he/she uses to mobilise the resources, the more powerful an actor is. For our analysis, it is particularly interesting which strategies actors use to assert their interests and how this leads to potential carbon lock-ins. Strategies include e.g. actors forming alliances and networks (Farla et al. 2012; Johnstone, Stirling, and Sovacool 2017), conventional lobbying (Johnstone, Stirling, and Sovacool 2017), or influencing expectations through discourses (Farla et al. 2012; Lockwood, Mitchell, and

Hoggett 2019; Becker, Beveridge, and Röhring 2016). At the same time, actors are constrained by the realms within which they operate (Wittmayer et al. 2017; Farla et al. 2012; A. Smith, Stirling, and Berkhout 2005; Becker, Beveridge, and Röhring 2016; F. W. Geels 2020).

Our analysis introduces a new approach to marrying material and perception analysis. While an analysis of material realities describes the context within which actors operate, it does not address how their agency depends on their perceptions of a specific situation (e.g. the systems' status quo or likely future developments). Thus, our approach provides the foundation for identifying the space for agency in shaping the energy transition by providing a roadmap for identifying the connection between material realities and actors' interests and strategies. Thereby, we gain a deeper understanding of the underlying lock-in mechanisms influencing the course of energy transitions.

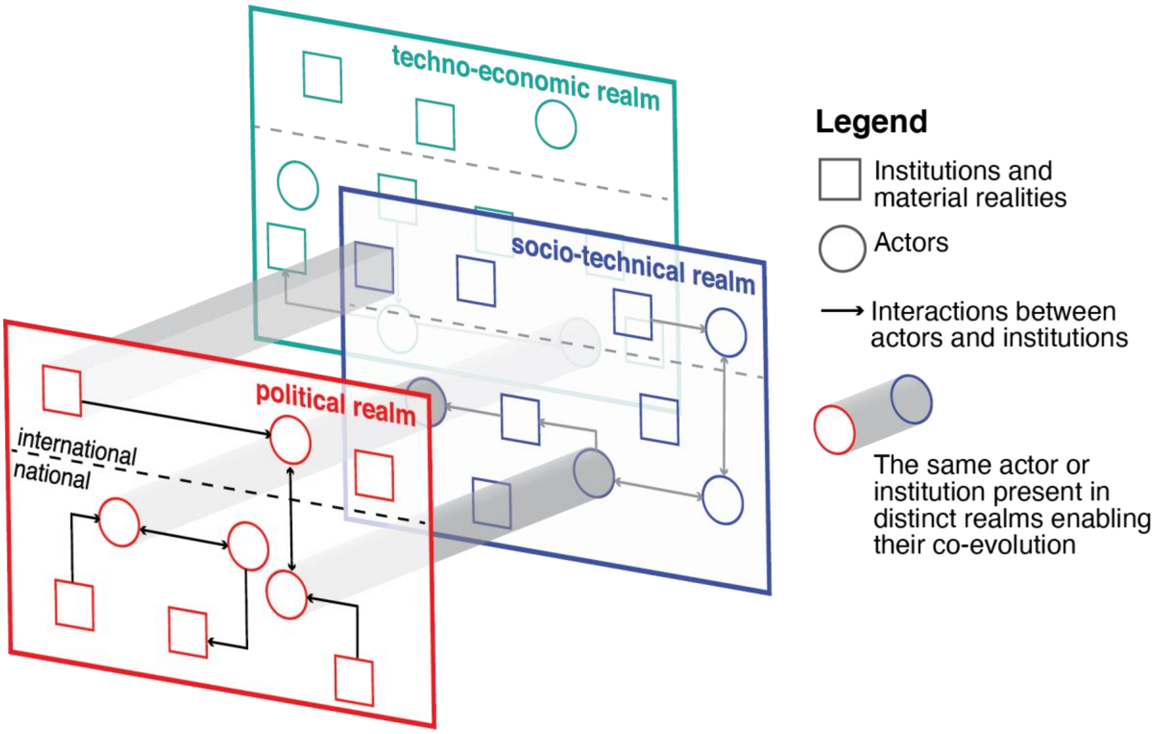

Figure 6: Actors influence the realms while the realms define the space for actors' perceptions and related strategic actions.

3.4 Methodological approach

In order to unpack the connections between the LNG terminals and a potential risk of a gas lock-in in the next phase of Germany's energy transition, we developed a methodological approach based on the theoretical foundation of Section 3.3. We thus identify the relevant developments in the three co-evolving realms through material analysis focused on the techno-economic, political, and socio-technical developments within each realm, complemented with an actor analysis focused on their interests, perceptions and interactions.

3.4.1 Material Analysis

Our material analysis is based on the aforementioned meta-theoretical framework (Cherp et al. 2018). In the following, we introduce the relevant variables of each realm (what is referred to as system in the original framework (Cherp et al. 2018)), we explain which variables were excluded due to a lack of relevance for our empirical case and how we covered the remaining ones in our analysis (also summarised in Table 5).

Political	State goals	Political interests	Institutions and capacities
Techno-economic	Resources	Demand	Infrastructure
Socio-technical	Innovation systems	Regimes and niches	Technology diffusion

Table 5: Main variables covered in respective realms.

Note: See (Cherp et al. 2018) for more detailed explanation of those variables.

The **political realm** covers actors and power. The main variables explaining the realm are *state goals, state capacities, political interests and institutions* (Cherp et al. 2018, 186). We have a special focus on *state goals* (energy security and climate change) and *political interests* of state, private and civil society actors. We neglect *state capacity* as a constraining variable in the German context, as Germany has a high state capacity with strong institutions and a high level of political stability. We also refrain from conducting an in-depth analysis of *institutions* ourselves, however, a coordinated market economy like Germany with federal states, politically stable and relatively wealthy, implies close interactions between the government and a strongly engaged civil society as well as powerful incumbents (F. W. Geels et al. 2016; P. Hall and Soskice 2001; Jacobsson and Lauber 2006). In policy issues regarding gas, the close state-industry interaction consists of a wide network between different private and public sector actors, e.g. lobby and industry associations, and the affected larger companies, such as the utilities and network operators. Official consultation processes, conferences and lobbying behind closed doors enable exchange.

Existing technologies and the related infrastructure as well as energy markets form the **techno-economic realm**. The main variables in this realm are *supply, demand and infrastructure*. We therefore analyse factors that influence the development of natural gas demand and supply in Germany, the existing natural gas infrastructure in Germany and the EU, and the resulting supply-demand balance. We base our analysis on collected primary data on existing natural gas infrastructure as well as expansion plans, gas consumption and relations with exporters. Additionally, we include scenarios as estimates for future supply and demand balance developments, so that interactions with other energy carriers, such as coal, nuclear energy and renewables are included as well.

The **socio-technical realm** comprises technological developments and social practices, summarised by the main variables *regime and niche, technology diffusion, and innovation systems*. The *technology diffusion* of LNG in Germany is characteristic of *regime* development but has interesting interlinkages with the *synthetic gas niche*, and their respective rules, practices, and meanings. LNG has been used for decades in other (EU) countries (Bouzarovski, Bradshaw, and Wochnik 2015) and the maturity of the relevant technologies is high (Mokhatab et al. 2014). Regasified LNG fed into the grid is no different from conventional pipeline natural gas, which is why no behaviour change is necessary and there is compatibility of actors along the value chain. The major innovation in LNG is at the global level within the *global innovation system* (Binz and Truffer 2017).[48] We hence focus our analysis of the socio-technical system on *regime dynamics* as characterised by the interlinkages of the *(liquefied) natural gas regime* and the influence of the *global innovation system* on national developments.

Our data collection for the material analysis includes (1) informational interviews with scientific experts and NGO representatives, (2) the participation in information and dialogue events on the local and national level throughout 2019 and 2020, (3) hosting a stakeholder workshop with 15 participants from the private sector and civil society (e.g. companies involved in gas distribution, LNG terminal planning, energy consultants and environmental NGOs) in May 2019. and (4) a desk study of current literature. So far, there is limited scientific literature on the LNG terminals in Germany, so we also considered grey literature (e.g. company reports, newspaper articles, and protocols from political debates).

3.4.2 Actor analysis

In order to identify the relevant actors in our case and to understand their interests, we conducted an actor analysis following Brugha and Varvasovsky (2000).[49] Our methodological procedure can be divided into five steps. In the first three iterative steps, we identified and clustered the relevant actors (based on the material analysis) who exercise power and/or have a substantial interest in German natural gas developments. In the last two steps, we obtained the actors' interests and perceptions, and analysed them. In the following, all steps are described in detail.[50]

1. **Identifying and clustering actors:** We have used the results of the material analysis to identify all relevant actors. From this extensive list, the authors and two additional scientific experts in the German and international natural gas market selected the most relevant actors, clustered them into actor groups, identified their position (supportive, non-mobilised or opposed), the strength of their interest in the project (low, medium, high), and their possibility to influence the process (low, medium, high). In our case, this process resulted in an actor matrix that included 23 actor groups.
2. **Narrowing down the field:** From that list, we excluded actor groups with only moderate or low interest and low or medium influence. In our case, this resulted in a matrix with no opposed actors. In order to avoid a bias in the investigation and to analyse the controversy around the terminals we included opposed actor groups.
3. **Categorising actor groups:** We categorised the actor groups into state, private sector and civil society actors and relevant subgroups (see Figure 7).

[48] Generally, technological innovation processes take place and are influenced on various levels, such as regional, national and international, and those levels interrelate [56]. This conceptualisation of technological innovation as multi-locational and with structural couplings (termed global innovation system) is helpful in our case to analyse the influence of global developments on the diffusion of LNG technology in Germany.

[49] While the term 'stakeholder' is used mostly in management literature, 'actor' is more common in the literature strand regarding energy transitions. To avoid confusion by using different terms, we always use 'actor' and therefore 'actor analysis' instead of 'stakeholder analysis'.

[50] Actor analysis as a methodology has been criticized for a lack of rigid criteria according to which actors are included or excluded from the analysis (Reed et al. 2009b). Therefore, we aim to present our approach as detailed and transparent as possible.

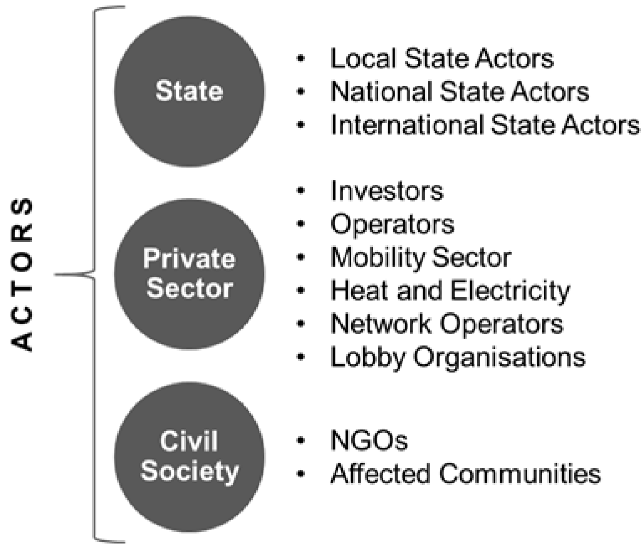

Figure 7: Main actor groups involved in the political processes surrounding LNG Terminal construction in Germany.

4. **Interviewing the relevant actor groups:** We conducted 14 semi-structured interviews with actors from each of those three actor groups. The interviews took place between July and October 2019. The interview guideline was structured in two parts, to identify both (1) the actors' interests with regard to the LNG terminals and (2) their perception on the material developments affecting German natural gas markets in general. In our analysis, we can thus establish linkages between actor interests and their perceptions of developments. In order to preserve the anonymity of the interviewees we have assigned acronyms to the interviewees, which will be used in the further text when quoting (see Table 6).

Number of interviews	Interviewees	Acronym*	Position**
4	State Actors (government, opposition, local and national)	Interview_SA	1 supportive/ 1 non-mobilised / 2 opposed
2	Academic experts	Interview_AE	1 opposed/ 1 supportive
2	Community Actor and NGO	Interview_CA	Opposed
6	Private Sector Actors	Interview_PSA	3 supportive/ 1 opposed/ 2 non-mobilised

Table 6: Summary of conducted interviews with acronyms.

** We identify the information used from the interviews by using the acronyms.*

*** The position of the actors was not always known beforehand but determined through the analysis of the interviews.*

5. **Analysing the interview results:** We processed the interview data using qualitative content analysis (Gläser and Laudel 2010b). We coded for the following 8 categories to identify the main aspects regarding the actors' interests and perceptions of the LNG terminals touching upon all three realms that could not be answered (solely) via a desktop research: 1) Actors' interests in the

specific LNG terminal proposals, as well as LNG and natural gas in general; 2) benefits and negative impacts of the terminals; 3) barriers to terminal construction; 4) collaboration and connections between actors; 5) position towards terminals; 6) effect of synthetic gases and 7) natural gas market trends' influence on LNG terminals; 8) possibilities and strategies of actors to influence political decisions regarding the terminals.

3.4.3 Triangulation of actor and material analysis

Our methodological contribution is this 5-step approach on how to combine a material analysis with an interview-based actor analysis. Through this, we can use a wide variety of data (documents and interview data) and cover both the realms and actors' perceptions to analyse the resulting mechanisms influencing energy transitions. We link actors' perceptions and interests with the material systems analysis (Section 3.5) and derive the most relevant mechanisms (Section 3.6), and are thereby able to answer the following questions: How do the material conditions around natural gas consumption and LNG infrastructure relate to and interact with relevant actors' perceptions and interests? How do these interactions shape systemic changes and create lock-ins for the German energy transition?

3.5 Results of realms and actor analysis

The results are structured by realm: Section 3.5.1 presents the political realm with its competing state goals as well as actors' perceptions of these state goals and political interests of key actors. Section 3.5.2 contrasts the natural gas supply and demand analysis with actors' perceptions of techno-economic developments regarding LNG and natural gas markets in the techno-economic realm. Finally, Section 3.5.3 describes the socio-technical realm by comparing the LNG and synthetic gas technology diffusion with actor perspectives on innovation. For each realm, we reflect on the role lock-in plays.

3.5.1 The political realm

3.5.1.1 Competing state goals

Gas infrastructure and the economics of LNG projects cannot be disentangled from the political environment. Politics here means two main things: the pursuit of state goals by political actors and the way in which private actors influence policy making.

One important state goal for a country that signed the Paris Agreement are greenhouse gas (GHG) emission reductions. If Germany's natural gas consumption stays at the 2018 level, emissions from natural gas alone (166 Mt CO_2-eq) would account for more than a quarter of Germany's total GHG emission target for 2030 (563 Mt CO_2-eq), or almost all emissions available to the energy sector in 2030 (183 Mt CO_2-eq), even without considering life-cycle emissions [8–11] (see Figure 8). If Germany is to meet its climate targets, natural gas would need to be reduced in the final energy consumption already before 2030 (as other energy carriers such as coal will be responsible for a share of the emission target as well), and to almost zero by 2050 (Kochems, Hermann, and Müller-Kirchenbauer 2018).

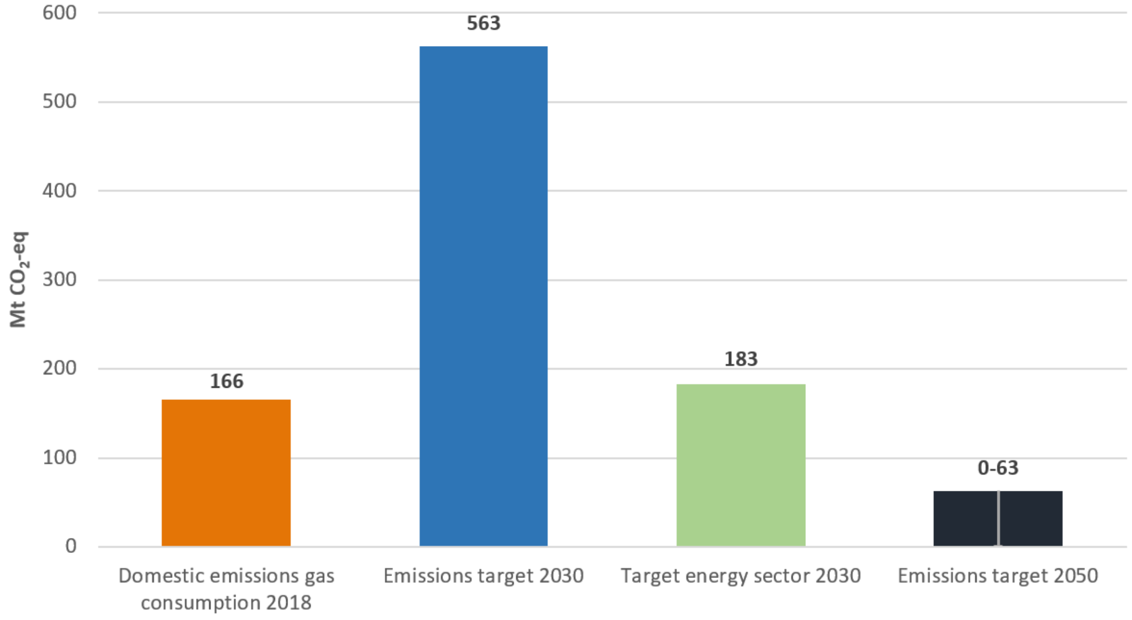

Figure 8: Comparison of current emissions from gas consumption and emission reduction targets for Germany.

Source: Authors' illustration based on (Breitkopf 2020; BMUB 2016; Pfluger, Tersteegen, and Franke 2017).

The main national state goal competing with climate protection is to balance energy demand with secure supply (Helm 2002). Following Cherp and Jewell (2014, 418), we define energy security as "low vulnerability of vital energy systems". We operationalise this definition looking at how LNG terminal construction would affect risks from *a)* political and *b)* technological/natural origin, as well as *c)* resilience of the energy system.

a) Risks of political origin can be diminished by reducing foreign control over energy systems.[51] As Germany only produces a small share of its gas domestically, it will not obtain full sovereignty over its natural gas supply. In 2017, Germany's energy import dependence was 64% overall, and 91% for natural gas.[52] An LNG terminal would not contribute to increasing energy sovereignty.

b) The increase of the *robustness* of an energy system helps to minimise technological or natural (resource depletion) risks. The Federal Ministry for Economic Affairs and Energy (henceforth Economics Ministry) states in its monitoring report on energy security and natural gas that supply of natural gas for Germany is "very secure" (BMWi 2019b) and that even without German LNG Terminal import infrastructure, via the EU internal market the worldwide LNG supply has a positive impact on German gas supply (BMWi 2019b, 13). Nevertheless, the construction of the

[51] Commonly known in energy security literature as sovereignty (Cherp and Jewell 2014).

[52] Eurostat. 2018. "Energy Import Dependency by Products: % of Imports in Total Energy Consumption." https://ec.europa.eu/eurostat/tgm/refreshTableAction.do?tab=table&plugin=1&pcode=sdg_07_50&language=en.

terminals can lead to a potential increase in robustness of gas supply security due to an increase of import capacities.

c) *Resilience* aims to create the ability of energy systems to respond to disruptions. The major supply security concern is related to Russia (Holz et al. 2017; Bouzarovski, Bradshaw, and Wochnik 2015). Especially since 2006, due to Russian disputes with the transit countries Ukraine and Belarus, and annexation of Crimea, public and political concerns about potential supply disruptions were high (Van de Graaf and Colgan 2017; Siddi 2018; Stulberg 2015; Orttung and Overland 2011; Stulberg 2017). To increase short-term resilience, LNG is unsuitable as contracting a new shipment and actual delivery would take in most cases several days. Only in the case of longer interruptions would the additional capacity of a terminal be useful.

Thus, while LNG could increase reliance on foreign sources, and therefore decreasing the sovereignty of the German energy system, it could slightly increase its robustness and resilience by installing a young infrastructure, diversifying imported sources and providing a buffer against import shocks. Energy security is shaped not only by material realities but also by perceptions of key actors.

One additional state goal, both on the national and the local level, is economic growth, which includes the provision of jobs as well as generation of revenues.

3.5.1.2 Perceptions of state goals and political interests

Central actors in the political system shaping LNG decisions are German national and local level state actors, natural gas interest associations as well as other states. Among these actors, the Economics Ministry and the US Government are the most dominant in the public discourse. Non-state actors such as NGOs and community actors are also trying to influence the process but from a far less powerful position.

The **Economics Ministry** is strongly supportive of LNG terminal construction in Germany, especially to reduce import dependency from Russia. However, the ministry also supports the construction of Nord Stream 2 and states that gas supply security is already high and can be guaranteed without the terminals. It sees synthetic gases and hydrogen imports as a possibility to bring LNG terminals in accordance with German climate protection targets [Interview_SA]. It also started the "Dialogue Process Gas 2030", that reiterated the importance of LNG for diversification, and a resulting gas grid expansion (BMWi 2019e).[53] The **Ministry of Environment** has not positioned itself publicly for or against the terminals, although concerns have been voiced during the interview about negative environmental and climate impacts [Interview_SA].

Local state actors from the federal states, where the three potential terminals are located, are interested in the projects as they might lead to employment opportunities, improve the regions attractiveness for new corporations potentially related improvements in street, railway and gas grid

[53] Interestingly, despite being called a stakeholder dialogue process, throughout the process mostly industry, energy sector and consulting representatives were part of it, while environmental NGOs were only included towards the end.

infrastructures. In addition, regional and local politicians have an interest in private sector investment that might reduce the needed amount of public investment in structurally weak regions [Interview_SA].[54]

The political support for the LNG Terminals is also influenced, both directly and indirectly, by **other states**, in particular the United States, Russia and the EU. Direct pressure to increase LNG imports comes from the US government, which aims to increase natural gas deliveries from the US to the EU (as part of the general strategy to keep their position as a natural gas exporter, which resulted from the shale gas fracking boom, see also 3.5.2.2). Several interviewees [Interview_SA x 3; Interview_AE; Interview_PSA; Interview_CA] alluded to the diplomatic pressure for the German government to follow the **US government**'s push to deliver gas to Germany, going so far as calling German state support for LNG a “friendship service” to the US [Interview_SA].[55] On the other hand, interviewees also mentioned concerns about a strong influence of **Russia** on the German natural gas market. Natural gas supplier diversification is often mentioned in the context of Russia being the largest gas supplier for Germany, and related vulnerability to natural gas price increases [Interview_SA; Interview_PSA].

Interest associations connect actors of the entire gas value chain in Germany, the EU and globally. Their general aim is to create business opportunities for firms in the gas industry, and to establish favourable political conditions for that. In Germany there are well-organised umbrella interest associations representing the natural gas industry, e.g. the German Technical and Scientific Association for Gas and Water (DVGW) or Zukunft Erdgas (‘Future Natural Gas’). They are generally in favour of the construction of LNG terminals in Germany, but are not directly (or at least not visibly) involved in lobbying for the terminals. In the case of the Brunsbüttel terminal, the interest organisation ‘Maritime LNG Platform’, is actively lobbying for its construction. The platform unites different actors, to create a larger negotiating power. They include industry actors (e.g., Shell, Vopak, MAN, Gasunie, FLUXYS) as well as harbour and shipping companies (Brunsbüttel Ports GmbH, AIDA Cruiser, Hapak-Lloyd). The interest of the association is to establish LNG as a fuel for both shipping and heavy-load road transport and to remove regulative barriers for LNG use [Interview_PSA; Interview_AE].

Opposition to the current LNG terminals comes from several **Non-Governmental Organisations (NGOs**), mostly due to climate change, but also general environmental and security concerns. A prominent example is DUH (Deutsche Umwelthilfe, Environmental Action Germany), which conducted legal reports, publicly raising security and environmental concerns regarding the construction of the LNG terminals. As a result, the operators in Wilhelmshaven need to find a different location for their FSRU, and in Brunsbüttel they are obliged to address the security concerns raised by the DUH as part of the approval process. Their overarching interest is to prevent the permission of investments that endanger local environments and negatively affect the climate [Interview_CA].

Local community actors are mostly indifferent to the realisation of the projects [Interview_SA; Interview_CA]. Several local actors are open to the project in the hope that additional jobs and an

[54] We interviewed a local representative from the Green Party, who positions himself against the terminals. He gave us an overview of reasons why other local politicians support the terminals.

[55] In a public statement the Economics minister also called it “a gesture towards the US administration“; Reuters. 2018. “Germany to build LNG plant in 'gesture' to U.S. drive to sell more” Accessed September 17, 2020. https://t1p.de/067b.

improvement of the local infrastructure will have a positive impact on them. However, some local citizen associations are actively against the terminals for environmental reasons and security concerns [Interview_CA].

An institutional gas lock-in exists, as both private and political actors and institutions profit from existing and additional natural gas projects and their role for energy provision and security. Political and market actors have therefore jointly advanced further regulations which benefit natural gas, such as the change of the gas network regulation and bonus payments when natural gas replaces coal (see Section 3.6). Such intentional choices further stabilise existing institutions, strengthening both national and international institutional connections.

The discursive debate is between LNG and natural gas being a “bridge fuel” and a “partner of renewable energy” versus a “barrier to the energy transition” and an “environmental risk” [Interview_SA; Interview_CA; Interview_PSA; Interview_AE] (Dodge and Metze 2017). It is part of the prevalent German energy transition and energy mix discourse since the 2000s (Buschmann and Oels 2019).

3.5.2 The techno-economic realm

3.5.2.1 The German gas market and its European context

Germany is the largest natural gas consumer in the EU. In 2018, the German gas consumption was 92 bcm (IEA 2019b). This represents 23% of the primary energy consumption (IEA 2019b; AG Energiebilanzen e.V. 2019a), while for example renewable energy sources contributed around 14% (AG Energiebilanzen e.V. 2019a). In 2018, natural gas accounted for 8% of electricity, 45% of the heating sector and 0.2% in the transport sector (AG Energiebilanzen e.V. 2019b).[56] In total, natural gas accounts for 24% of Germany’s CO_2-eq emissions.[57]

Importantly, Germany’s gas supply depends on other countries, as the country imports more than 90% of its natural gas consumption: In 2018, 44 bcm came from Russia, 34 bcm from the Netherlands and 22 bcm from Norway (3 bcm unspecified, 33 bcm re-exports) (AG Energiebilanzen e.V. 2019c; IEA 2019b; 2018). Germany has an extensive gas infrastructure, which includes more than 515,000 km of gas pipelines, cross border connections to all its neighbours, as well as Russia and Norway, as well as the largest gas storage capacities in the EU (~23 bcm, corresponding to around a quarter of annual German consumption) (Kochems, Hermann, and Müller-Kirchenbauer 2018; ENTSO-G 2019). Several planned gas infrastructure investments include a second pipeline to Russia (Nord Stream 2), a second pipeline from the Baltic Coast to the Czech Republic (EUGAL), and converting pipelines and appliances running on low-calorific gas to high-calorific gas (due to decreasing imports from the Netherlands). The gas grids are highly regulated and managed by gas transmission system operators (16 companies) and gas distribution network operators (>700 different companies). Due to its geographical location and existing storage facilities, Germany acts as a "gas hub" for Europe (Viebahn et al. 2018, 878).

[56] Umweltbundesamt. 2021. “Energieverbrauch nach Energieträgern und Sektoren.“ Accessed September 20, 2021. https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren.

[57] Statista. 2020. “Energiebedingte CO2-Emissionen in Deutschland nach Energieträger im Jahresvergleich 2000 und 2018.“ Accessed February 20, 2023). https://t1p.de/84q6.

In contrast to Germany, the EU as a whole already has considerable LNG import capacities – sufficient to cover around 43% of its current gas demand (as of 2015) (EC 2016). The largest import capacities are in Spain, followed by the UK and France (Yafimava 2020).[58] The average utilisation rate of EU LNG terminals varies over time – in 2011 the utilisation rate was only around 50% and it decreased to less than 25% in 2017 before rising in 2019 to the 2011 level (ACER and CEER 2018; EC 2019a; ACER and CEER 2012). LNG imported via a terminal can then be used either in its liquid form, or it can be regasified and put into the gas grid.

3.5.2.2 Natural gas supply and demand analysis

Current security of *supply* concerns stem from the fact that continental European natural gas production is declining. The Netherlands plan to phase-out gas production from the Groningen field in 2022 (Government of the Netherlands 2019) and there is a widespread belief that the Norwegian gas fields are in decline (Söderbergh, Jakobsson, and Aleklett 2009; M. Hall 2018) (however, the Norwegian Petroleum Directorate argues that production from currently undeveloped fields could lead to an increase in Norwegian exports (Prognos 2017)).[59]

The growing global LNG market has attracted more actors in recent years, among them the US (IGU 2019) driven by the fracking boom, which resulted in an in a ten-fold increase in exports in only four years.[60] Support for LNG originates in the aim to decrease imports from Russia. Yet, in 2019, Russia was the second largest LNG supplier to the EU (with Qatar being the largest supplier).[61] Hence, it is possible that in case of LNG terminal construction, Germany would also buy more LNG from Russia than the US, which would prevent the desired supplier diversification.

For LNG consumption economic prospects have improved, however not enough to make investments in LNG terminals profitable enough for quick private sector investments in Germany. Final investment decisions have been repeatedly postponed for Brunsbüttel as well as Wilhelmshaven. Concerns about demand for natural gas are exacerbated by COVID-19 (IEA 2020b).

In 2018, 45% of heat production in Germany came from natural gas (AG Energiebilanzen e.V. 2019b). Expansion of renewable energy use for heating has stalled since 2012 (UBA 2020). Since the German coal phase-out law from July 2020 financially incentivises the conversion from coal-fired power plants not only to renewable energies but also to natural gas, it is unlikely that the overall demand for natural gas in heat provision will fall. Gas use in the electricity sector depends on whether renewable energy and efficiency improvements will compensate for the phase-out of coal and nuclear energy. The transport sector in Germany is under pressure to achieve its emission reduction targets. LNG would

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[58] Terminals exist also in Italy, the Netherlands, Belgium, Portugal, Greece, Poland, Lithuania, and Malta.

[59] See also Norwegian Petroleum. 2019. “Recent Activity.” Accessed December 6, 2019. https://www.norskpetroleum.no/en/developments-and-operations/recent-activity/.

[60] EIA. 2019. “Liquefied U.S. Natural Gas Exports by Vessel and Truck (MMcf).” Accessed February 18, 2023. https://www.eia.gov/dnav/ng/hist/ngm_epg0_evt_nus-z00_mmcfa.htm.

[61] In 2019, Russia exported 16 Mt of LNG to the EU, while the US exported 12 Mt (Qatar as largest supplier delivered 21 Mt to the EU) (according to S&P Global Platts data, for quarterly data see EC (2019a)); Petroleum Economist. 2020. “Russia beating US in LNG price war”. Accessed February 18, 2023. https://pemedianetwork.com/petroleum-economist/articles/gas-lng/2020/russia-beating-us-in-lng-price-war.

provide several actors of the mobility sector with the chance to change towards a fuel, which is similar to their old business model from a technology perspective, while being able to reduce emissions of several pollutants. For this reason, there is currently a trend to use more LNG in transport (especially heavy-duty traffic and shipping; the absolute amounts of natural gas use are nevertheless still very small, see Section 3.5.2.1). Subsidies and other beneficial regulations implemented for LNG in the transport sector include e.g. a reduction in energy taxation for natural gas for vehicles (BFJ 2019), the exemption of LNG trucks from toll charges, and the creation an official “LNG-Taskforce”.[62] However, studies show that switching to LNG in the transport sector does not necessarily lead to a reduction of GHGs (J. Köhler et al. 2018).[63] Other countries, such as the UK, have decided in their mobility strategy not to consider LNG as a climate friendly fuel option.[64]

In contrast to some actors’ expectations of an increasing natural gas demand, a multi-model comparison shows that in modelling results in line with the Paris Agreement (or merely an 80% GHG emission reduction by 2050) natural gas demand decreases, even before 2030 (Kochems, Hermann, and Müller-Kirchenbauer 2018; FNB Gas 2019). A study by the German Environmental Agency shows that ambitious climate protection would render unnecessary up to 74% of all gas distribution grids due to a reduction in gas consumption (Wachsmuth et al. 2019).

3.5.2.3 Economic interests of key actors

In general, gas market actors, such as gas traders, pipeline operators and utilities, have an interest in increasing gas consumption in Germany. An expansion of the gas infrastructure and additional natural gas imports can strengthen their business and increase the value of their asset, whereas a strong decline of gas consumption would negatively affect their business models. **Gas traders** have an interest in the flexibility provided by LNG in contrast to pipeline gas, as one terminal can be used to import gas from a variety of suppliers and offers the possibility of short term contracting in case of a changing gas demand or prices [Interview_PSA]. **Utilities** experience pressure due to the nuclear and coal phase-out and the need to find dispatchable sources. Gas is close to their old business model and therefore a convenient substitute.

The **industry sector** was responsible for 40% of Germany’s total gas and 47% of its electricity consumption in 2018. Industrial actors have, hence, a particular interest in low gas prices, for cheap electricity and heat provision, as well as feedstock [Interview_PSA x2; Interview_AE]. **International suppliers** have an interest to access the largest European gas market to sell their LNG.

Gas grid operators’ business model is threatened by a potential reduction in gas demand. They could benefit from an increase in gas throughput in case of LNG deliveries, especially the ones connecting

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[62] Dena. 2016. “Flüssigerdgas: LNG-Taskforce legt Arbeitsschwerpunkte fest.” Accessed February 18, 2023. https://www.dena.de/newsroom/meldungen/fluessigerdgas-lng-taskforce-legt-arbeitsschwerpunkte-fest/. Dena. 2021. “LNG-Taskforce und Initiative Erdgasmobilität.” Accessed February 18, 2023. https://t1p.de/6fhc.

[63] The reduction of GHGs depends on various factors, such as the origin of the fuel, the engine design and the associated methane leakage. Depending on how these factors interact, a possible reduction of GHG is between -20% and +3%.

[64] GOV.UK. 2019. “Written statement to Parliament Clean maritime plan.” Accessed February 18, 2023. https://t1p.de/0k95.

pipelines and the ones close by. Another option are synthetic gases, which is why some gas grid operators start investing in “hydrogen ready” infrastructure.

For actors in the **mobility sector**, LNG is an opportunity to meet short-term emission reduction targets (e.g. CO_2, NO_x, SO_x), opening investment opportunities for trucks, long-distance shipping and inland vessels and related infrastructure, such as filling stations [Interview_AE, Interview_PSA].

Relatively **few** of the gas market actors are **opposed** to the LNG terminal construction in Germany. One example is an association of municipal utilities, which opposes the allocation of the access pipelines’ costs to gas customers, but not the terminals themselves.[65]

Germany has a well-developed natural gas infrastructure that many actors are interested to continue to avoid stranded assets. An infrastructural natural gas lock-in exists due to the long lifetime and large sunk costs of existing infrastructure. Additional investments would reinforce the infrastructural lock-in. Especially in the heat sector, a strong technological lock-in exists, as renewable heating alternatives are not yet widespread and would require a different infrastructure, rendering e.g. the natural gas distribution network unnecessary (Hanmer and Abram 2017).

3.5.3 The socio-technical realm

3.5.3.1 Gas regime technology diffusion and synthetic gas niche

The *natural gas regime* is influential. It is dominant and well connected across different sectors (electricity, heat, industry, and to an increasing extent transport) and actors (gas network operators, corporations of various industries using gas as input for heat or as feedstock, manufacturers of gas appliances, municipal and nationwide utilities, gas storage operators, traders, several political actors, etc.), through, for example, joint interest associations. LNG is a part of the highly institutionalised natural gas regime, as the actors and formal and informal rules are mostly the same, and one of the shared beliefs is that natural gas should play an important role in the energy transition.

There is an emerging *synthetic gas niche*, to utilise (renewable) electricity to produce hydrogen with electrolysers (Wulf, Linßen, and Zapp 2018).[66] Hydrogen has long been promoted as an alternative (see e.g. IEA (2019d) for “previous waves of enthusiasm for hydrogen” since the 1970s) and this trend has re-emerged now in connection with increasing pressure on the natural gas regime (Stern 2019; von Hirschhausen, Praeger, and Kemfert 2020).[67] To produce renewable synthetic gases domestically, Germany would need to substantially expand the capacity of electrolysers, but also additional renewable energy capacities to produce the needed electricity (Wulf, Linßen, and Zapp 2018, 2018; ewi 2017; Fraunhofer 2019). Due to space constraints for additional renewable capacities and related societal opposition, imports of synthetic gases would need to play a substantial role (ewi 2017; Fraunhofer 2019).

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[65] VSHEW. 2019. “Scharfe Kritik des VSHEW an Förderung des Brunsbütteler Flüssiggasterminals.” Accessed February 18, 2023. https://www.presseportal.de/pm/117618/4302191.

[66] In a second step – the methanisation – hydrogen can be converted into methane.

[67] One example for the pressure is the company ‘Total’ complaining about the European Investment Bank stopping to finance investments in unabated gas projects, from 2021 onwards, stating that “Gas has never been so much criticised in Europe”; Reuters. 2019. “UPDATE 1-Energy group Total criticises EIB's decision not to finance gas.” Accessed February 18, 2023. https://t1p.de/1cz7.

The assumptions about imports are made without actual existing projects in other countries on the required scale to provide those import possibilities, and partnerships are in an early stage.

In the debate about the LNG terminals, the possibility to use the planned terminals for hydrogen imports is often mentioned, despite the fact that the technical requirements are very different for hydrogen and not fulfilled by the terminal (see (2017) for a comparison of LNG and liquid hydrogen properties). Synthetic methane could potentially be imported via the terminals, but the costs and available supplies are still highly uncertain.

In general, the high level of natural gas use in various sectors facilitates support for LNG. The (*liquefied) natural gas regime* also shares many rules, values and goals with the *synthetic gas niche*, creating in many instances a further alliance instead of competition.

3.5.3.2 Actor perceptions of innovation

Various private sector actors and state actors referred to the possibility of importing *synthetic gases* (i.e. hydrogen) via the terminals [Interview_PSA x2; Interview_SA]. However, there is not a large market for synthetic gases and market actors stated that they had no concrete plans for those imports, as the uncertainty about price developments and possible suppliers is too high. Nevertheless, synthetic gases are strongly present in the discourse on the energy transition. One important actor in this context is the "Power to X Alliance". Among the members of this association are car manufacturers, transmission grid operators and natural gas traders.[68] The alliance demands the construction of 5 GW electrolyser capacity[69] by 2025 and changes to regulation to facilitate the market entry of 'Power to X' technologies.[70] Central actors from the renewable industry, like the umbrella association of renewable energy[71], are not part of it.

Hydrogen does influence the debate in the socio-technical realm and could encourage some actors to support the construction of the terminals. However, given the still immature technological development and incompatibility of hydrogen with LNG import terminal technology, it is unlikely that there will be any actual synergies.

The natural gas regime is well connected to political actors. Regime actors use their resources to promote their technological preferences, create strong networks, achieve beneficial regulation, a supportive public discourse, and mobilise public funding for their projects.[72] The combination of the efforts of regime actors creates effective regime resistance.

Generally, LNG and synthetic gases relate to a behavioural lock-in of natural gas, as utilities and other companies are used to large-scale energy infrastructure and trade, and customers are familiar and

[68] Power to X Allianz. 2021 "Allianzpartner." Accessed February 18, 2023. https://www.ptx-allianz.de/ueber-uns/allianzpartner/.

[69] Used to generate hydrogen from electricity.

[70] Power to X Allianz. 2021. "10-Punkte-Plan zur Nationalen Wasserstoffstrategie – Power to X durch Anwendungsoffenheit zum Erfolg führen. Accessed February 18, 2023. https://t1p.de/aw16. 'Power to X' refers to the conversion of electricity to gases, heat, or liquids, often used to improve storability of electricity.

[71] German Renewable Energy Federation (BEE).

[72] Next to the support for LNG, the German hydrogen strategy, provides e.g. €7 billion for the creation of a hydrogen industry (Bundesregierung 2020).

satisfied with gas boilers and district heating grids. Regasified LNG requires no change of standards or any change in behaviour of consumers or companies along the value chain, enabling the continuation of the status quo.

3.6 Mechanisms explaining LNG support in Germany

The main mechanisms to explain political support for LNG terminals are summarised in Figure 9. The three realms are linked through the relevant actors, which enhance co-evolution via their actions. The mechanisms can explain the observed reciprocal developments of the three realms as well as perceptions and actions by the actors. The mechanisms are explained in detail in the following and can be divided in those that represent one form of lock-in (defined in Section 3.3), and those that more generally support natural gas as a technology.

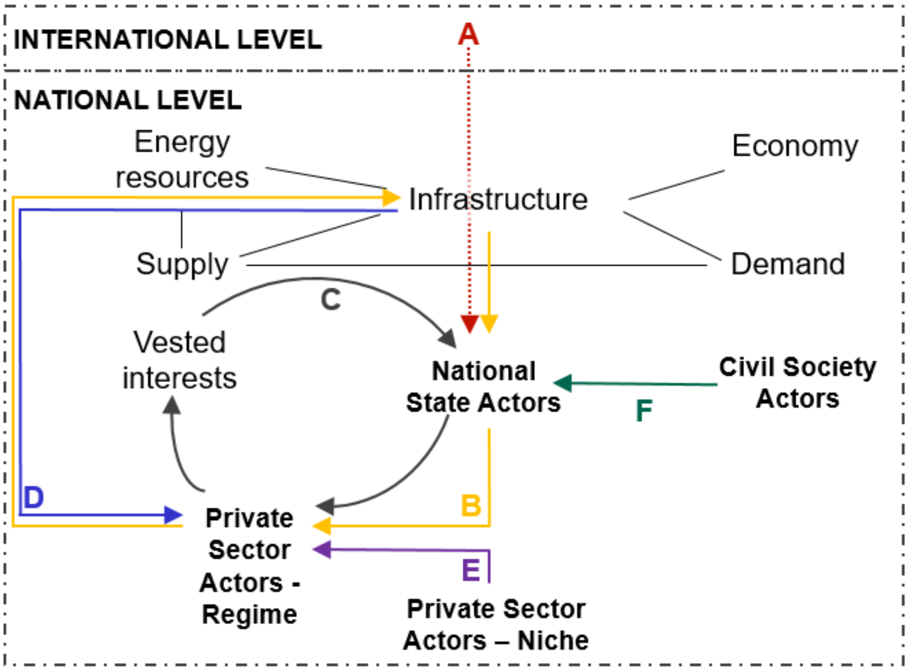

Figure 9: Explanatory mechanisms for political support for LNG investments in Germany.

Notes**:** Each mechanism is designated by a specific colour and letter. A – International diplomacy pressures German state actors to support LNG; B – State actors support incumbents to ensure a secure supply-demand balance; C – Regimes enable beneficial regulation through promoting the alignment of their vested interests with political interests; D - Sunk investments reduce willingness for change; E - Niche innovations strengthen the gas regime; F – Weak opposition of actors outside the regime poses no counterweight.

Source**:** Adopted from (Cherp et al. 2017).

A – Pressure on German state actors to support LNG through international diplomacy: Institutional lock-in

One of the general mechanisms that creates political support for LNG terminals is international diplomacy: Since the shale gas boom turned the US into a natural gas exporter (see Section 3.5.2.2), the Trump administration was putting increasing pressure on both the EU as a whole and Germany in particular to import more gas from the US. The outcome of national dynamics in other countries is included here, however, a detailed analysis of those dynamics – e.g. what is leading US politicians to act the way they do – is beyond the boundaries of the analysis and the framework.

Illustrative for this mechanism are for example meetings between US and European state actors regarding the so called "trade war" in July 2018, when EU commissioner Juncker and US President Trump agreed on EU purchases of LNG from the US in the context of the threat of US punitive trade tariffs. Since then, LNG imports from the US to the EU have risen sharply, albeit from a very low level (EC 2019b).[73] Reasons for the increase are, however, not only the political pressure but also various global LNG market developments (see 3.1 and Section 3.5.2). A conference on US LNG organised by the German Economics Ministry in February 2019 is another illustration for the pressure the US is putting on the German government to support imports of US LNG: Only US politicians and corporations but no actors e.g. from Qatar or Russia were invited. As a preliminary result of the conference, a key-issues paper of the Economics ministry proposed the changes to the network regulation in favour of LNG infrastructure projects (BMWi 2019a). In December 2019, the US officially imposed sanctions on companies involved in the construction of Nord Stream 2, against which the US government has officially positioned itself.[74] Together, the measures taken by the US – trying to stop more infrastructure enabling gas imports from Russia and pushing the EU to import US LNG – are putting the German state in a difficult situation: It needs to respond to this larger geopolitical conflict between Russia and the US, while aiming to guarantee high supply security and low energy prices. In this context, finance minister Scholz proposed in a now publicly available non-paper to the US Secretary of the Treasury that Germany would support the Brunsbüttel and Wilhelmshaven LNG terminals with up to €1 billion, if in return the US would stop sanctions related to Nord Stream 2.[75]

The simultaneously decreasing natural gas production in central Europe (especially in the Netherlands and possibly Norway) reinforces beliefs of various actors that Germany and the EU as a whole are vulnerable to Russian gas supplies, which in turn intensifies mechanism B.

What makes the German gas market particularly attractive to the US is its size and that it acts as a gas hub in Europe. Thus, while other European countries will be subject to similar supply constraints from decreasing continental European gas production, it is not clear if the US would put the same pressure on other European countries.

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[73] See also European Commission. 2018. "Joint U.S.-EU Statement Following President Juncker's Visit to the White House." Accessed August 25, 2018. https://ec.europa.eu/commission/presscorner/detail/en/STATEMENT_18_4687.

[74] SEC. 7503, National Defense Authorization Act for Fiscal Year 2020, https://www.congress.gov/116/bills/s1790/BILLS-116s1790enr.pdf.

[75] Federal Ministry of Finance. 2020. "Non Paper Germany Nord Stream 2/U.S. LNG." Accessed February 18, 2023. https://t1p.de/s7cq.

B – State actors support incumbents to ensure a secure supply-demand balance: Institutional lock-in

In consideration of the decreasing natural gas production within the EU and internationally low LNG prices, the support of private sector investments in LNG terminals can help state actors to create higher supply security levels by facilitating imports from additional supplier states (or at least the perception of higher energy security) (see Section 3.5.1.1). This mechanism therefore represents an institutional lock-in mechanism. On the international supply side, the aforementioned decreasing European natural gas production increases supply security concerns, and low international LNG prices reduce the barrier for investments and increase the attractiveness of natural gas use.

The extent to which supply security would actually increase through the LNG terminals is contentious for various reasons: (1) LNG might not be contracted and shipped rapidly enough to function as an emergency supply mechanism [Interview_PSA], (2) LNG supplies might come from Russia and therefore may not provide diversification, (3) the Economics Ministry states that supply security would also be guaranteed without the construction [Interview_SA], (4) as well as studies showing that EU gas supply is secure without new investments (Artelys 2020; Holz et al. 2017).

Despite a rather small increase in supply security and the repeated statement that the LNG terminals are a private sector investment (Interview_SA, Interview_PSA, Deutscher Bundestag (2018)), the federal and state governments support the construction in various ways, to close acknowledged "substantial profitability gaps"[76]. The main measure by the government was the change of the Gas Network Access Regulation in March 2019. Thus, the Economics Ministry overturned a previous decision by the German network regulator (BNetzA) from December 2018 that investors would have to bear the cost for pipelines connecting the terminals to the gas grid themselves.[77] Now, 90% of the investment costs and 100% of the operating costs for the connecting pipelines will have to be borne by gas consumers through a rise in network charges.[78] Interestingly, the related entire political process was only several weeks long, which has been evaluated as unusually quick and surprising by different interviewees [Interview_PSA x2]. For these connecting pipelines, additional changes to the rest of the gas grid become necessary, as it would not have sufficient capacities to transfer the additional supplies. These additional grid expansion plans might cause additional costs of €800 million, which would again have to be borne by gas consumers and not the terminal operators (DUH 2020).

[76] E.g. by the Federal Government Coordinator for the Maritime Industry Norbert Brackmann or the State Secretary of the Ministry of Economic Affairs, Transport, Employment, Technology and Tourism of Land Schleswig-Holstein Stratmann, Klaus. 2018. "Warum Deutschlands erstes Flüssiggas-Terminal ein Befreiungsschlag wäre." Accessed Februar 18, 2023. https://t1p.de/txb3.

[77] BMWi. 2019. "Verordnung zur Verbesserung der Rahmenbedingungen für den Aufbau der LNG-Infrastruktur in Deutschland. Accessed February 18, 2023. https://t1p.de/2jqn. (Ordinance to improve the framework conditions for the development of LNG infrastructure in Germany).

[78] Daniljuk, Malte. 2019. "Erdgas wird die neue Kohle." Accessed February 18, 2023. https://www.heise.de/tp/features/Erdgas-wird-die-neue-Kohle-4398966.html.

The terminals are also financially supported through direct federal state subsidies for LNG terminal construction[79] and through the common task budget "Improvement of the Regional Economic Structure".[80] Further political support for the terminals consists of general governmental support, such as economics minister Altmaier stating repeatedly that he expects the construction of terminals to go ahead, as it would be good for supply security, and encouraging companies to apply for public funding.[81] The relevance of this becomes starker when compared to the stalling wind energy expansion without increasing political support. The financial as well as discursive governmental support is particularly interesting, as no final investment decision has been made yet by any of the potential project investors. This suggests that the terminals are not necessarily financially viable without supportive measures.

The parallel coal and nuclear phase-outs increase the pressure on private sector and state actors to ensure a stable and affordable energy provision. Besides the technical requirements, especially state actors also need to create public trust in their strategy to achieve this. A well-known and established energy source, such as natural gas, continues to be promoted as a reliable and relatively climate friendly fuel. It is claimed that natural gas can fill this role more easily than renewables and new storage technologies. Effectively, climate concerns and environmental concerns are thereby dominated by short-term economic and energy security concerns (see Sections 3.5.1.1 and 3.5.1.2).

The German coal commission and coal phase-out law illustrate political side games regarding natural gas: While the process of negotiating the pathway and related support for affected regions and companies was supposed to focus on coal, natural gas is mentioned repeatedly. New gas power plants are now to be granted a facilitated construction process (BMWi 2019c), and the coal phase-out law[82] encourages the conversion of coal-fired power plants to gas via a financial "coal replacement bonus" (Kohleausstiegsgesetz § 7c).

Several elements of this mechanism are likely to be replicated also in other EU countries[83]: That states work with incumbents to ensure a supply-demand balance is a well-known phenomenon, and refers to an institutional lock-in (Cherp et al. 2018). Like Germany, other countries, such as Spain, Portugal or the United Kingdom, are now in the next phase of their energy transition, where they are phasing out coal, and face an increase in natural gas use.

[79] Süddeutsche Zeitung. 2020. "Finanzausschuss stimmt Investitionspaket zu." Accessed February 18, 2023. https://t1p.de/u4o7.

[80] Besides that, natural gas and LNG consumption are encouraged through a wide variety of different measures, e.g. the mobility and fuel strategy (Deutscher Bundestag 2018), as well as via tax rebates for LNG use, financial benefits for research and development and the development of LNG fuelling infrastructure (M. Hall 2018; Prognos 2017).

[81] Daniljuk, Malte. 2019. Op. cit.

[82] Bundesregierung. 2020. „Gesetz zur Reduzierung und zur Beendigung der Kohleverstromung und zur Änderung weiterer Gesetze." Accessed February 18, 2023. https://www.bmwk.de/Redaktion/DE/Artikel/Service/kohleausstiegsgesetz.html.

[83] Currently, LNG import terminals are under construction in Finland, Italy, Poland and Spain, while proposals exist in Croatia, Estonia, Finland, France, Ireland, Latvia, Netherlands, Romania, Spain and the United Kingdom (Inman 2020).

C – Regimes enable beneficial regulation through promoting the alignment of their vested interests with political interests: Regime resistance

Gas regime actors promote their vested interests as to be aligned with local governments' and communities' interests. For example, when the proposals for the LNG terminal were presented to local politicians in Brunsbüttel (a comparatively structurally weak region), hopes for infrastructure improvements, such as railways and roads, were specifically addressed [Interview_SA]. In addition, potential positive effects, such as local jobs or tax revenues, were used to argue for financial and regulatory support.

Another strategy of private sector regime actors is to threaten state actors with moving their projects abroad. Since this would harm the local economy, politicians are more inclined to create support for their business. For instance, in Brunsbüttel, Yara[84] has mentioned to local policy-makers the possibility to close its production facilities, if the LNG terminal and a resulting better gas grid connection would not be built [Interview_SA].

"So the entire area is too poorly connected to the natural gas grid. The industry companies now come and say, if that won't get better […] then we won't invest here in the future. Of course, this also causes fear and panic. There's no question about that. Of course, they pursue their own interests […], and we as the little volunteer councillors here, get told so. And then you are confronted with a responsibility. […] You can't just dismiss it and say it's shenanigans, what they say, it is definitely not. There is a good bit of truth in it somehow. But it's hard for us to judge whether they won't invest more in the future or whether it's just one of those threatening backdrops that are being built up." [Interview_SA].

This direct lobbying works especially well through strong existing networks between the natural gas industry, interest associations and politicians. For example, companies involved in the LNG terminal payed political lobby institutions, such as the von Beust & Coll consulting, to advocate for the terminals[85] [Interview_PSA]. The consulting firm created the "Maritime LNG Plattform e.V." (see Section 3.5.1.2), which unites various actors along the value chain. Jointly they benefit from a more advantageous position to lobby state actors for political support. The consulting firm directly advertises their influence through using different party contacts, known from former political work [Interview_PSA x2] (e.g. from Ole von Beust, the former mayor from Hamburg from 2001 to 2010).[86]

A main strategy from larger gas interest associations is to present natural gas as a benefit for supply security, affordable energy, and as necessary for economic growth. The gas industry also advocates for the "partnership" between renewables and gas (Haas 2019), again managing to create at least the perception of complementarity instead of competition.

This is also the case when LNG terminals are framed as a means to import "green gases". Noteworthy is the presentation of plans to use the terminals in the long run for hydrogen, despite the different

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[84] Yara is one of the five single biggest gas consumers in Germany (0.7 bcm in Brunsbüttel; ~1% of German gas consumption). Boyens Medien. 2018. "Gute Ernte: Yara in Brunsbüttel." Accessed February 18, 2023. https://t1p.de/ftxs.

[85] In this case especially the Brunsbüttel terminal.

[86] They themselves call the platform the "joint" between economy and politics and "partners" of the economics and transport ministries. von Beust & Coll, see https://www.vbcoll.de/.

technical requirements that would need a different terminal design and substantial reconstructing with high costs (Klebanoff, Pratt, and LaFleur 2017) (see also Section 3.5.3).

In general, the gas regime managed to introduce the narrative of gas being ‘climate and environmentally friendly’ and a ‘bridge fuel’ in the public discourse (see also (Delborne et al. 2020)). These cognitive frames have not been significantly challenged yet by opposition, which is why they contribute to reinforcing misguided public beliefs and facilitate gaining public and political support (Fitzgerald, Braunger, and Brauers 2019).

This strategy is a well-observed phenomenon in many countries. On the European level, since 2010, the five main oil and gas corporations and their lobby groups have spent at least €250 million to influence European decision-making.[87] Together these different strategies represent a form of lock-in termed regime resistance, used by the regime to shape ideas about problems and solutions, to advance their own interests, and to prevent stronger regulation. While the strategy has oftentimes proven successful, it is worth noting that in some EU countries, such as Sweden, natural gas has not been strengthened substantially despite an advanced, next phase (Markard 2018) of the energy transition.

D – Sunk investments reduce willingness for change: Infrastructural lock-in

An important barrier to using less natural gas are past investments: The related sunk costs push actors to keep using that infrastructure, as they cannot recover the already incurred costs. This mechanism is, hence, a form of infrastructural lock-in. Incumbents have an incentive to frame gas infrastructure as a valuable asset that should be used long-term. However, almost two-thirds of all gas distribution grids would not be needed anymore for natural gas distribution, if climate targets were to be fulfilled (see Section 3.5.2.2). One relatively small change for distribution grid operators or power plants is to invest in so-called “hydrogen ready” infrastructure.[88] This vague term encompasses infrastructure with varying capabilities to integrate hydrogen (between single-digit percentage levels and 100%), mostly creating a further lock-in but no systemic changes. Additional investments in gas infrastructure lead to an increase of an already existing gas lock-in. The scale is, among other factors, dependent on the expected lifetime of investments and the financial barrier to switch to renewable alternatives as well as system-wide institutional effects (Erickson et al. 2015; Unruh 2000). Most gas infrastructure has relatively long expected lifetimes, e.g. LNG terminals at least 20-40 years, new ships equipped with LNG as power unit ~65 years, and gas-fired power plants at least 20-30 years. The quantitative analysis of the additional lock-in’s extent is beyond the scope of this analysis and remains a proposal for future research.

E – Niche innovations strengthen the gas regime

States often nurture niches in parallel with working with incumbents, and do not choose either or (as e.g. shown in (Cherp et al. 2017)). The German state supports the strengthening of the niche by financially supporting domestic synthetic gas production (e.g. electrolysers for hydrogen production).

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[87] CEO, Food and Water Watch and Friends of the Earth Europe. 2019. “Big Oil and gas buying influence in Brussels.” Accessed February 18, 2023. https://t1p.de/lxnb.

[88] Another possible response strategy would be to stop new investments in a coordinated way to avoid stranded investments. This happens in the Netherlands, where gas distribution operators pushed the government to introduce policies ending natural gas grid connections in new build homes, as they would not have been able to recover those costs when the Netherlands phase-out natural gas by 2050 [personal conversation with Dutch energy expert].

Additionally, imports of synthetic gases (i.e. renewable methane and hydrogen) are discussed and cooperation with other states is planned (Bundesregierung 2020).

However, the gas case is special, as the natural gas regime builds a network with the gas niche: The synthetic gas niche, including diverse synthetic and renewable gases (see (Timmerberg, Kaltschmitt, and Finkbeiner 2020; Hainsch et al. 2020) for a typology), poses no competition to natural gas yet, but actually supports the natural gas regime (of which the LNG regime is a part), as it consists of very similar infrastructure and actors. Even strong growth of synthetic gases (via domestic production or imports) would not constitute a competition for the gas regime but mostly a useful new element to it (e.g. increased supply for the gas grid and power plants, new investment opportunities for equipment suitable for a high hydrogen share, etc.). It would also not imply major changes of rules or routines. Therefore, we find that the synthetic gas niche (e.g. hydrogen) is not a threat but a complement to the existing natural gas regime.

Despite the slow development of the various synthetic and biogenic gases (little investment, high costs, limited space and partly missing technological readiness), political debates are prominent and (financial) political support has already been promised (see e.g. Germany’s hydrogen strategy (Bundesregierung 2020)).

This mechanism may also be replicated at the EU level and in other European countries, as the new prominence of synthetic gases in policy debates is increasing rapidly.

F – Weak opposition of actors outside the regime poses no counterweight

Opposition to natural gas in Germany is now slowly emerging. The most visible one is DUH, which commissioned legal reports on the Brunsbüttel, Stade and Wilhelmshaven terminals, raising concerns about the legal feasibility of approval for the terminals. For Brunsbüttel, feasibility is disputed especially on grounds of security risks, e.g. due to the immediate vicinity of a nuclear power plant and an interim storage facility for radioactive waste (Ziehm 2019a). For the FSRU in Wilhelmshaven, environmental and safety concerns evolve especially around extensive waterway construction, continuous maintenance dredging works, and the location being close to several nature protection zones (Ziehm 2019b). The legal reports see the construction of the terminals as incompatible with the existing major accident laws in all three locations, as well as the existing climate law (Ziehm 2019a; 2019b; 2020). The aspects mentioned in the legal reports need to be included in the approval processes of the terminals, such as the related planning permission hearings and the environmental impact assessments. This might have complicated or slowed down the approval [Interview_PSA]. Despite attempts by political actors at the state level to undermine the legitimacy of the legal report, the approval process for none of the terminals has been completed yet. Additionally, some local opposition by citizen initiatives exists. Those actors opposed to the terminals describe presswork as difficult, since e.g. the local newspapers benefit financially from advertisements by the terminal operators [Interview_CA].

In general, opposition by these few actors is small compared to the strong support by a wide variety of political and private actors in favour. NGOs and citizen initiatives are more fragmented and additionally their involvement targeting natural gas is much lower than e.g. compared to nuclear energy and coal, where they exerted strong opposition (Oei et al. 2018; Johnstone and Stirling 2020). Opposition to LNG terminals is being organised in other constituencies than those of the LNG terminal locations, and jointly across countries. How German NGOs strategies (especially regarding the legal reports) influence LNG terminal construction might be used as lessons learned by other organisations.

Together, those six mechanisms can explain political support for LNG in Germany. Four mechanisms (A, B, C & D) represent the institutional and infrastructure lock-in, as well as regime resistance. Additionally, two other mechanisms are not directly lock-in mechanisms, but still facilitate the development of LNG terminals and use of natural gas (E & F). Together, they illustrate the stable lock-in of natural gas in Germany:

(1) An institutional lock-in of gas results from the pressure of international state actors and domestic incumbents. The course of political decisions is shifted due to the influence of special interests to the expansion of natural gas use, and therefore the support of LNG. As the opposition has so far been weak, and the personal and institutional connections are not nearly as strong as the ones of the existing regime, it could not break up the existing institutional lock-ins. However, due to legal interference in the projects, the opposition might still have a large impact by at least delaying and potentially preventing the construction of the terminals.

(2) An infrastructure lock-in is particularly related to potentially stranded assets of long-lived natural gas infrastructure, such as LNG terminals, but also pipelines and power plants. The fear of lost profits or destruction of values already prevents stronger regulation on natural gas, and would increase with additional infrastructure investments. As the synthetic gas niche does not pose an actual competition to the existing natural gas regime and would use the same infrastructure, the continuation or an even higher infrastructure lock-in is likely.

(3) The behavioural lock-in is more important on the consumer side and the heating sector, but the LNG terminals nevertheless also illustrate a behavioural lock-in, as the natural gas industry can continue and potentially even strengthen the status quo of their business with additional LNG supplies. A behaviour change is unnecessary, as regasified LNG fed into the grid is no different from conventional pipeline gas. Regime resistance fostered political support and beneficial regulation and advances the interests of the natural gas regime.

(4) A discursive lock-in exists, as the narrative of gas being a ‘climate friendly’ ‘bridge fuel’ is still dominant in the public discourse. It prevents a necessary debate about the barriers natural gas poses to advanced energy transitions and the change towards renewable energies by justifying natural gas use.

3.7 Conclusion

In this paper, we analysed the case of LNG terminal investment plans and related state support in Germany. This is particularly interesting because Germany promotes an energy transition towards renewable energies, but risks an increasing lock-in of the fossil fuel natural gas, contradicting GHG emission reduction targets. We analysed the material conditions around natural gas consumption and LNG infrastructure, and the interaction with relevant actors' perceptions and interests. This enabled us to identify the main lock-in mechanisms of LNG and natural gas, as well as other mechanisms generally supporting the role of natural gas in Germany. Together they can explain the political support for LNG terminal construction.

By linking the lock-in concept with the meta-theoretical energy transitions framework by Cherp et al. (Cherp et al. 2018) as well as an actor analysis, we make a theoretical contribution to the energy transitions literature: In particular, we showed how actors walk between different realms, which shape energy transitions to enable or block change. This relationship with lock-ins will become increasingly important as they are key to understanding inertia and change in accelerating energy transitions. Our methodological contribution lies in a 5-step approach on how to combine a material analysis with an interview-based actor analysis.

This comprehensive approach enabled us to identify six mechanisms creating state support for LNG terminals. Two mechanisms represent institutional lock-in: A) pressure on German state actors to support LNG through international diplomacy and B) state actors supporting incumbents to ensure a secure supply-demand balance. Mechanism C) finding that regimes enable beneficial regulation through promoting the alignment of their vested interests with political interests is a form of regime resistance, while mechanism D) is a case of infrastructural lock-in, as sunk investments reduce the willingness for change. Two other mechanisms benefit natural gas's position in general: E) niche innovations strengthening the natural gas regime, and F) a weak opposition posing no counterweight to the regime.

In general, the strength of a well-anchored gas regime would be threatened by an ambitious climate policy. Thus, political lobbying tries to increase gas consumption in various sectors and construct new gas import capacities. Germany, despite its relatively high climate ambition, is providing strong state support to LNG, which risks leading to an increasing natural gas lock-in, even as natural gas consumption today is already inconsistent with future climate targets.

The development of German gas is interesting from a climate perspective, given that the country represents almost 25% of EU-27 natural gas consumption in 2019.[89] Additionally, we deem the German case to hold lessons for the development of LNG in other European countries as they reach the 'next phase' of the energy transition. Many European countries already use natural gas, and now face similar challenges to Germany of managing a coal phase-out along with growing variable shares of renewables. We hold that our findings are particularly relevant to those countries in a similar energy situation and with a coastline to possibly install more LNG terminals, such as Spain, Portugal, or the United Kingdom.[90] How the international and national factors we identified play out in different states will shape to what extent the insights from the German LNG case are transferrable. All EU countries have closely linked energy markets. Diplomatic pressure from exporting countries could be a major challenge for the next phase of the energy transition. However, the degree of pressure they receive from international actors may differ due to the relative size and importance of their markets in the EU gas markets.

The perception of natural gas as a comparatively clean fuel and its link to synthetic gas will likely shape the development of LNG in all states. The discourse on and optimism about synthetic gases strengthens the natural gas regime generally, as they open a window of opportunity for political inertia in the sense that no unpopular decisions on a demand reduction have to be taken. Instead, the status quo can be

[89] Eurostat. 2020. "Supply, Transformation and Consumption of Gas." Accessed February 18, 2023. https://ec.europa.eu/eurostat/databrowser/view/nrg_cb_gas/default/table?lang=en.

[90] In Spain, two further terminals are currently under construction, while in the UK a proposal for an addition terminal exists.

prolonged with the promise that natural gas will be replaced by synthetic gases at a later stage of the transition process. With the current immaturity of these technologies, this is a risky path. The relative importance of this lock-in mechanism will be shaped by the role of natural gas and synthetic gases in the countries' decarbonisation strategies. Finally, the well-observed phenomenon of states working with incumbents will likely be replicated. However, the strength of the natural gas regimes varies as well as the perception of the importance of natural gas for energy security.

As this is a case study on only one country, preliminary conclusions for other countries need to interpreted with caution. Also, more aspects of the natural gas sector besides LNG need to be analysed to understand the full lock-in. Another limitation of this research is that actors might have had incentives not to share all of their actual interests and plans in the interviews, which in turn might have altered the findings. As further research, we deem valuable a quantification of the GHG lock-in, and further qualitative analyses of natural gas lock-ins in other countries and sectors.

The main resulting recommendation for policy-makers would be to include lock-in risks in calculations for their decision-making: Especially when planning the ongoing energy transition, the risks for an accelerated transition posed by stranded asset, but also institutional, infrastructural, behavioural and discursive lock-ins need to be accounted for. To avoid an increasing natural gas lock-in and resulting negative economic and ecological impacts, natural gas infrastructure investments would need to be aligned with climate policy targets, and not only seen in a security of supply context. Otherwise, natural gas could crowd out investments in renewables and thereby slow down the shift to low-carbon energy sources. In addition, measurements of methane emissions and targets for methane emission reductions could help to reduce the climate impact. We also want to encourage further research on the role of natural gas in energy transitions, and the question how an increasing lock-in can be prevented.

Part 2: Governance strategies for overcoming path dependencies and preventing lock-ins from natural gas

4 Chapter 4: Communal heat planning: Overcoming the path-dependency of natural gas?

4.1 Introduction

In July 2021, the European Climate Law came into force, legally binding its Member States to reduce greenhouse gas emissions by 55 percent by 2030 (compared to 1990) and achieve climate neutrality by 2050.[91] This implies the phase-out of fossil energy sources. However, in 2020, the share of renewable energy (incl. hydro) in primary energy consumption in the EU was only 18 percent, while oil (36 percent), natural gas (25 percent), and coal (11 percent) still provide the majority of energy (bp 2021). While phasing out coal has already been decided in several Member States, natural gas (NG) is often still advocated as the "cleanest" among all fossil fuels. Most recently, this is reflected in the EU Taxonomy Regulation, which is intended to steer financial capital towards a European Green Deal, where NG was classified as "sustainable" (EC 2022b). However, a rising number of publications show that NG is not a sustainable energy source. The problem of methane leakage[92] has been pointed out since the 1990s (Okken 1990; Rodhe 1990). An alarming increasing in methane concentration in the atmosphere is observable (Nisbet et al. 2019). The contribution of the usage of fossil fuels to this has been largely underestimated (Schwietzke et al. 2016) as well as the leakage rates of NG during its extraction, transport and use (Alvarez et al. 2018). The use of NG should therefore end as soon as possible.

In order to achieve the NG phase-out, it is of central importance to decarbonise low-temperature heat, which accounts for around 40 percent of the total NG consumption in the EU.[93] Only a very small proportion[94] is used to provide district heating (DH), while the majority is consumed in decentralised building heat (Bertelsen and Vad Mathiesen 2020). This requires an extensive NG transmission network. In addition to 200,000 km of high-pressure transmission pipelines, the EU-28 has a low-pressure distribution network of more than 2 million kilometres. Figure 10 shows that the distribution network covers a large part of the EU countries.[95]

Due to the heat transition, the future of NG distribution networks is uncertain. Firstly, demand for NG will decrease because of a decrease in overall low-temperature heat consumption, due to e.g. modernisation measures in old buildings and higher efficiency standards in new buildings. Secondly, electrification of decentralised heat supply and the expansion of DH will lead to a further significant decline in NG demand (EC 2018). The fact that gas consumption (NG, hydrogen and synthetic methane) in buildings and in the service sector within the EU will decrease by 2030 and even more significantly by 2050, if we stick to the climate targets, is also shown by various energy system scenarios (Shell 2018; IEA 2020c; EC 2020c; Matthes et al. 2018). It is therefore already apparent today that a large part

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[91] This chapter is under review at *Environmental Innovation and Societal Transitions* (03/2022). Single author original research article.

[92] Natural gas consists of more than 90 percent of methane, a short-lived greenhouse gas. During the extraction, transport and use of NG, the greenhouse gas is emitted into the atmosphere through leaks in the infrastructure (Anderson and Broderick 2017).

[93] ACER. 2022. Op. cit.

[94] 44 percent of energy consumption in residential heating was covered by NG in 2015, of which only 14 percent were used for DH and the remaining 86 percent in individual boilers (Bertelsen and Vad Mathiesen 2020).

[95] More then 40 percent of all households in the EU are connected to the NG network (ACER 2022).

of the distribution network will no longer be operated in the long term, but will have to be gradually decommissioned.

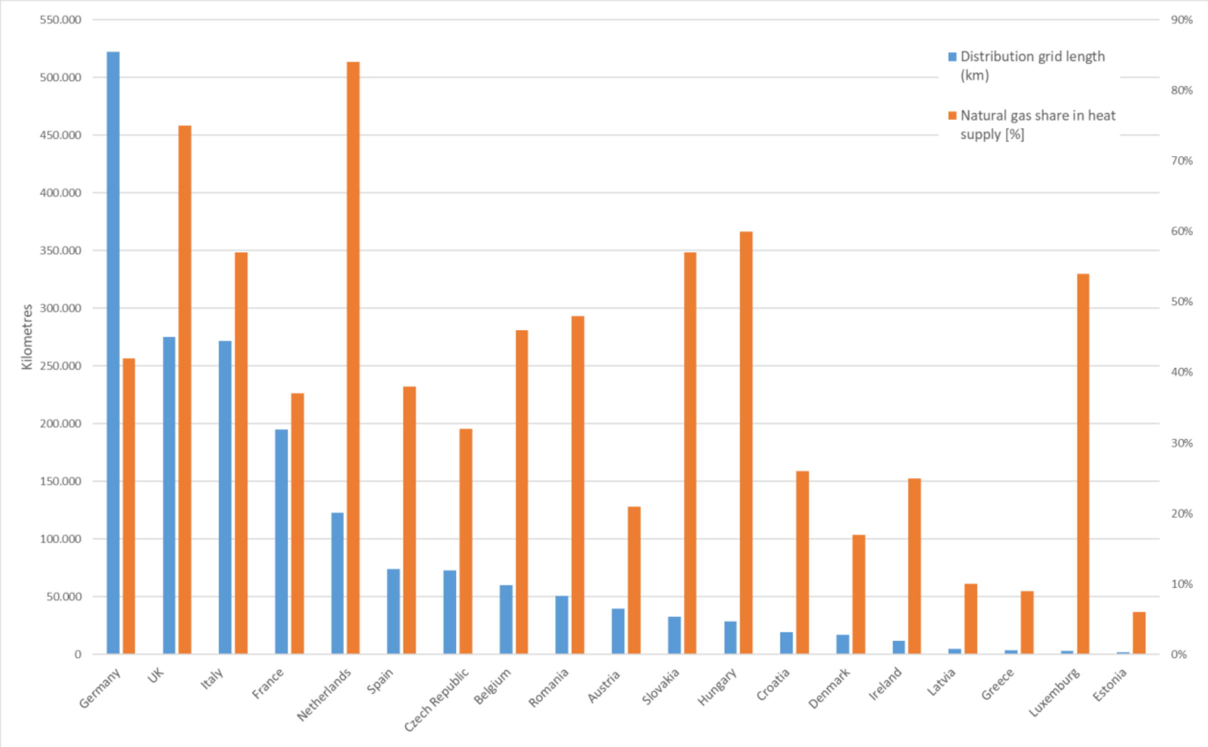

Figure 10: Distribution networks in the EU-28 and share of natural gas in the provision of decentralised building heat in 2015.

Source: Own depiction based on (Terlouw et al. 2019; HERA 2020; IEA 2021c; Gas Networks Ireland 2020; ILR 2019; ANRE 2019; Watson, Lomas, and Buswell 2019).[96]

However, the successful implementation of the heat transition and the related decommissioning of the NG distribution network can be slowed down or completely blocked by path dependencies. The use of NG in low-temperature heat supply is an established socio-technical system and path dependencies exist due to long-lived network infrastructure, its institutional and discursive embedding, as well as adapted behavioural patterns (Gross and Hanna 2019; Seto et al. 2016; Buschmann and Oels 2019). Therefore, governance strategies are needed for a long-term and forward-looking heat transition aimed at interrupting these path dependencies and thus preventing a lock-in of NG. However, even though the heat transition is increasingly becoming the focus of scientific and political attention, the question of the future of NG distribution networks has not yet been sufficiently addressed (Then, Hein, et al. 2020; Then, Spalthoff, et al. 2020; Däuper et al. 2018; Gross and Hanna 2019).

[96] And the following sources: Danish Energy Agency. 2022. "The Danish Natural Gas Transport System." Accessed February 18, 2023. https://ens.dk/en/our-responsibilities/natural-gas; MVM Group. 2020. "Providing Energy." Accessed February 18, 2023. https://www.mvm.hu/-/media/MVMHu/Documents/Tevekenysegunk/MVMCegbemutato/MVM-corporate-profile_20210601_ANGOL.pdf?la=en; Synergrid. 2007. "Energy Grids Serving Society." Accessed March 3, 2022. http://www.synergrid.be/download.cfm?fileId=synergrid_EN.pdf&language_code=NED.

One possible instrument for planning and implementing the heat transition in the long term is *communal heat planning* in which the municipalities are given far-reaching competencies. This instrument was developed and successfully used in Denmark in the 1970s to overcome the dependence on oil for heating (Sovacool and Martiskainen 2020; Chittum and Østergaard 2014). However, the Danish case differs in important aspects from future heat transitions, e.g. the transition was economically induced, and the existing DH infrastructure continue to be used. To what extent this approach is also suitable for the planning and implementation of a politically driven heat transition, including the phase-out of NG and the decommissioning of distribution networks in the EU countries concerned, is the subject of this paper.

The case of Germany is particularly well suited for this analysis. It has the largest NG distribution network in the EU (see Figure 10) and high investments are made in the expansion and maintenance of the networks every year.[97] As in other European countries, there is no strategy yet on how to plan and implement the decommissioning of this infrastructure. In the state of Baden-Württemberg, however, it was decided in the Climate Protection Act at the end of 2020 that the instrument of communal heat planning should be used to make the residential heat supply in the 103 largest municipalities (50% of the population) climate-neutral by 2040 (State Parliament of Baden-Württemberg 2021). *This paper analyses whether municipal heat planning, as stipulated in the Climate Protection Act of Baden-Württemberg, is a suitable instrument to overcome path dependencies through existing NG distribution networks and to implement a partial decommissioning of the networks.* For this purpose, I evaluated policy documents, scientific analyses and studies, and conducted interviews and background talks with 25 experts at the local, regional and federal level.

The remainder of the paper is structured as follows: Section 4.2 provides background information and presents the relevant literature for this analysis. Section 4.3 describes how communal heat planning is implemented in Baden-Württemberg. The methodological approach is outlined in Section 4.4. Section 4.5 presents the results of this work and is divided into two aspects. 4.5.1 describes path dependencies that can be tackled by communal heat planning, and 4.5.2 outlines the institutional, infrastructural/economic, behavioural and discursive path dependencies that need to be addressed with other measures. Finally, Section 4.6 discusses the results and concludes the work.

4.2 Background and Literature

This section presents the relevant literature to the three aspects that are substantial for this analysis: path dependencies and carbon lock-in (section 4.2.1), governance strategies of historical heat transitions (section 4.2.2), and the future role of NG distribution grids (section 4.2.3). In section 4.2.4, I outline my own contribution.

4.2.1 Path dependency and carbon lock-in

Heating systems require large and long-lived infrastructure that develops over decades, backed up by a range of policies helping to improve technology performance, network adaptation as well as consumer confidence and adaptation (Sahni et al. 2017). This leads to an efficient operating of heating systems

[97] In 2019 alone, distribution system operators (DNOs) invested 1.5 billion euros in their networks (BNetzA and BKartA 2021, 364–65).

but also creates path dependencies which can hamper the transformation of the system (Gross and Hanna 2019). In the case of a fossil-fuel-based system, this process is defined as carbon lock-in (Unruh 2000; Seto et al. 2016). Seto et al. (2016) conceptualised three major types of carbon lock-in: a) technological and infrastructural, b) institutional, and c) behavioural. Buschmann and Oels (2019) highlight that d) discourse can also foster the lock-in of a system.

As shown in the introduction, path dependency of NG in the residential heating sector in the EU is high. NG profits from a “clean” image. There is an extensive NG distribution network in place, and its development and maintenance are subject to complex regulations. NG is very consumer-friendly, as it requires little space and produces no dirt, noise or odour. However, as also shown in the introduction, the use of NG contributes even more to global warming than previously assumed and must therefore be overcome as quickly as possible. Since the infrastructure is very long-lived, the course for the phase-out must be set today in order to prevent lock-ins.

4.2.2 Governance of historical heat transitions

Major conversions of heat system within a short time period have already taken place in the past in the European countries UK, Norway, Finland, Denmark and Sweden. In all cases, economic factors have been at least one of the main drivers for the changes. In UK, the exploitation of NG resources in the North Sea caused a switch from biomass and town gas to NG during the 1960s and 1970s (Sovacool and Martiskainen 2020; Arapostathis, Pearson, and Foxon 2014). Rising electricity prices encouraged a shift from direct electric heating towards heat pumps and DH in Norway in the 1990s (Sahni et al. 2017). In Sweden, Denmark or Finland, the transition was initially a response to the rising prices caused by the oil crisis in the 1970s (Roberts and Geels 2019; Chittum and Østergaard 2014; Lauttamäki and Hyysalo 2019; Dzebo and Nykvist 2017).

A further key element in all cases was the harnessing of network externalities. Existing infrastructure continued to be used instead of becoming redundant (Gross and Hanna 2019), for example, the gas grid in the UK (Arapostathis, Pearson, and Foxon 2014; Arapostathis et al. 2013) or DH systems in Sweden, Finland and Denmark (Dzebo and Nykvist 2017; Roberts and Geels 2019; Lauttamäki and Hyysalo 2019). At the same time, the oil industry was weakened, leading to little to no incumbent regime resisting the transition policies (Roberts and Geels 2019; Dzebo and Nykvist 2017), and there was wider social acceptance or even support for the transition due to the fear of rising oil prices (Roberts and Geels 2019).

While important path dependencies were weakened by changing conditions in these historical cases, the transformation has nevertheless been guided by political instruments in all cases. Table 7 summarises the applied policy measures mentioned in the existing literature on those heat transitions. This not only shows that technological and economic developments are relevant to a successful transformation, but that it also requires the right policies and governance strategies.

Lock-in types	Measures	Examples
Infrastructural	Financial incentives/ Fair distribution of gains and burdens	• Subsidies for the conversion of heating systems for private building owners • Loans and investment subsidies for the construction of new heating and energy infrastructure
	Long-term planning	• Stable heat plans for long time periods • Consideration of investments in DH as very safe and reliable
Institutional	Legal measures	• Obligation to connect to DH grid • Prohibition of certain technologies in specific areas
	Organizational multiplicity	• Significant autonomy to local governments • Active involvement of a diverse number of stakeholders • Close interlinking of national and local heating policy
Behavioural	Knowledge building	• Technology and knowledge development • Involvement of important actors in networks (to encourage learning processes) • Experimentation and flexibility
	Confidence-building	• Quality control/high product standards • Strong price control and transparency for DH
Discursive	Communication	• Information campaign addressed to consumers

Table 7: Governance components of successful historical heat transitions.

Source: Own compilation, based on (Dzebo and Nykvist 2017; Lauttamäki and Hyysalo 2019; Gross and Hanna 2019; Sovacool and Martiskainen 2020; Roberts and Geels 2019; Chittum and Østergaard 2014; Eikeland and Inderberg 2016; Arapostathis et al. 2013; Arapostathis, Pearson, and Foxon 2014)

4.2.3 The future role of natural gas distribution grids

How the provision of low-temperature heat can be decarbonised or substituted is currently the subject of scientific debate. Some studies assume that synthetic gases can be used as a decarbonisation strategy (Dodds and McDowall 2013).[98] Other assessments, however, consider the use of synthetic gases in decentralised building heat unlikely, due to the lack of availability in the required extent (Zwickl-Bernhard and Auer 2022) or due to it not being economical (Hobley 2019; McGlade et al. 2018). They consider greater electrification in building heat more likely (Qadrdan et al. 2019).

In a systematic literature review, compiling existing technical and economic knowledge on the decarbonisation of gas grids, Speirs et al (2018) conclude that it is not yet clear whether existing NG grids are even suitable for transporting hydrogen safely. In addition, there is a lack of comprehensive analyses that compare not only the costs of gas and electricity storage but also the "*full suite of flexibility options, including electricity interconnection, demand side management, back-up gas electricity generation and all gas and electricity storage options*" (p. 295).

Regardless of the different possible heat transition paths, gas distribution networks will have a significantly lower throughput, and parts of the networks will not be able to continue to operate economically (Then, Hein, et al. 2020; Then, Spalthoff, et al. 2020; Däuper et al. 2018; Qadrdan et al.

[98] They assume an emission reduction of 85 percent, the availability of carbon capture transport and storage (CCTS) technologies, and that the conversion of NG networks to hydrogen does not cause any costs.

2019; Hickey et al. 2019). According to Then, Spalthoff, et al. (2020), a political debate on the topic is urgently needed so that a desirable solution from a societal perspective can be found.

Zwickl-Bernhard and Auer (2022) argue that possible stranded assets should not be decisive for how scenarios are designed or which paths should be taken politically. They therefore focus on electrification and DH systems and show that this path can be economically favourable in the long term despite stranded assets.

4.2.4 Author's contribution

Existing literature shows that path dependencies and resulting lock-in mechanisms have an impeding effect on transitions. Historic heat transitions differ in key aspects from future ones and can thus not directly serve as blueprints for successful governance strategies to overcome path dependencies. However, they show that policy measures are important in this regard. In upcoming heat transitions, the extensive NG distribution networks bear great risk for carbon lock-in. The existing literature about the effects of the heat transition on NG distribution networks shows that a decline in NG consumption has negative impact on the operation of the networks and needs to be managed politically.

However, there is a lack of research on how to govern such a phase-out of NG for residential heating and the resulting decommissioning of distribution networks. I aim to help fill this gap with my paper by showing to what extent the instrument of municipal heat planning is suitable to overcome path dependencies caused by distribution networks. Furthermore, I identify lock-in potentials of all four types and outline possible policy measures on the federal, state and municipal level that can help to overcome path dependencies.

4.3 Case Description

A long-term and forward-looking governance strategy for the transition of the heating infrastructure in the EU must consider that heat and electricity transitions differ in central aspects. Heat cannot be transported over long distances and must therefore be produced regionally. The potential for renewable heat and waste heat differs from region to region and thus also the required infrastructure. Furthermore, the existing heat supply infrastructure differs. This locally heterogeneous structures complicate centralised planning. Instead, a local approach seems to be more promising.

Germany is a particularly interesting case to analyse since the country has an extensive NG infrastructure and relies strongly on NG in the residential heat sector. In 2019, the length of the distribution networks were 522,000 kilometres, and approximately 13 million households were connected (BNetzA and BKartA 2021, 332). Its value is estimated to be around 270 billion euros (DVGW 2021). In 2020, NG accounted for 45 percent of residential heating (Schmidt et al. 2021, 17).[99] It is seen as a reliable energy source among consumers due to its low price volatility[100] and high security of supply

[99] 24 percent oil, 14 percent biomass, 10 percent district heating, 4 percent electricity (Schmidt et al. 2021, 17).

[100] Prices for an average residential customer ranged between 5.47 to 6.84 cents/kWh from 2010 to 2020. Verivox. 2022. "Verivox - Verbraucherpreisindex Gas." Verivox - Verbraucherpreisindex Gas. Accessed December 21, 2022. https://www.verivox.de/gas/verbraucherpreisindex/.

(BNetzA and BKartA 2021). However, the currently exploding prices[101], supply and security concerns for NG might damage its image.

While in practice the NG infrastructure is being further expanded, the “long-term scenarios for the transformation of the energy system in Germany”, which are being modelled on behalf of the German Economics Ministry, forecast a different trend. All three “extreme scenarios” show a decline in NG distribution networks, and, even in the power to gas extreme scenario, approximately only half of the operational network capacity in 2020 will be needed in 2050. An expansion of grids is not planned in any of the three scenarios, even by 2030 (Fraunhofer ISI 2021). In this context, several German states are pushing communal heat planning (Hamburg, Schleswig-Holstein, Bremen and Baden-Württemberg) (B. Köhler et al. 2021). The state of Baden-Württemberg is the most advanced in this process and therefore provides a good case study.

In Baden-Württemberg, communal heating planning became mandatory for the 103 largest municipalities (50 percent of the population) in December 2020 (State Parliament of Baden-Württemberg 2021, sec. 7c) (see Figure 11). To support the municipalities in the preparation and to ensure a certain uniformity of the heat plans, the State Energy Agency has developed a guideline in close cooperation with pilot municipalities as well as experienced planning offices. The guideline contains detailed information on the four steps of communal heat planning as required by law: *Inventory Analysis*, *Potential Analysis*, *Establishment of a Target Scenario*, and *Development of a Heating Strategy*[102] (Klimaschutz- und Energieagentur Baden-Württemberg GmbH 2020).

[101] 8.83 cent/kwh in November 2021. Verivox. 2022. Op. cit.

[102] “Municipal heat plans define the following for the overall territory of each municipality, divided by area 1. Systematic and qualified recording of current heating requirements or consumption and the resulting greenhouse gas emissions, including information on available building types and building age classes, as well as the current supply structure (existing building analysis), 2. Potential areas within the municipalities for reducing heating requirements by improving building efficiency and obtaining a climate-neutral heat supply from renewable energy, waste heat and cogeneration (potential analysis) and 3. A climate-neutral scenario for the year 2050, with interim targets for the year 2030, for the future development of heating needs, and a full description of the supply structure planned to cover requirements in a manner that is climate-neutral. Building on these defined elements, the municipal heat plan will outline potential strategies and measures for improving energy efficiency, and thereby reducing heating energy requirements and covering such requirements in a climate-neutral manner. At least five measures must be included that can begin to be implemented within the five years following publication” (State Parliament of Baden-Württemberg 2021, sec. 7c).

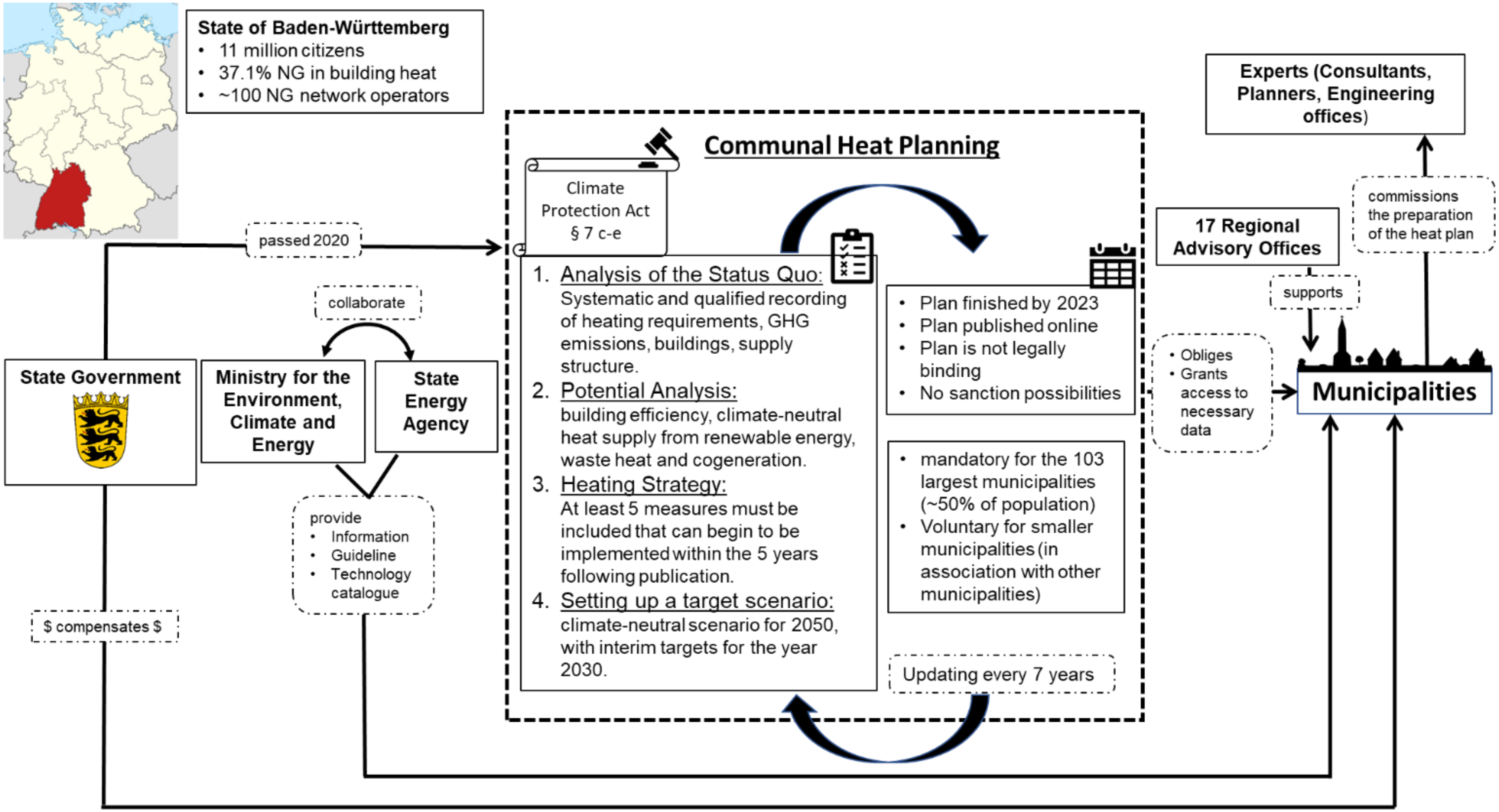

Figure 11: Communal heat planning in Baden-Württemberg.

Source: Own depiction based on (Klimaschutz- und Energieagentur Baden-Württemberg GmbH 2020).

4.4 Methodology

The data for this paper is based primarily on interviews with representatives of the most relevant stakeholder groups in the heat transition in Baden-Württemberg. I conducted 20 semi-structured interviews and five informal background talks with experts between October and December 2021 in German.[103] This included actors from the local level (representatives from municipalities, local energy utilities, and DNOs), the regional/state level (regional advisory offices, consultants, civil society, and state actors) and the national/federal level (law experts and scientists). For the interviews, I used a standardised interview guide tailored to the specific actor group, while the background talks were more open in their structure, but with a stronger focus on the expert's respective area of expertise.

Actors	Number of interviews	Acronym*
Municipal members	3	MM
Regional advisory offices	6	RAO
Municipal utilities	2	MU
Network operators	1	NO
Consultants	2	C
Law experts	2	LE
Civil society	1	CS
State actors	3	SA
Background talks (scientific and economic experts)	5	BT

* I use the acronyms to identify the information used from the interviews.

Table 8: Interviews and background talks.

To design the interview guidelines, in addition to the theoretical literature on carbon lock-in and path dependency (Seto et al. 2016; Unruh 2000), I conducted an extensive document analysis on heat planning and NG distribution network infrastructure. I considered scientific publications, publications by various political actors as well as studies and reports by research institutes and think tanks.

The interviews were analysed using qualitative content analysis (Gläser and Laudel 2010a). For this purpose, the interview transcripts and protocols were coded using MaxQDA software. The coding scheme contained the codes evaluation of communal heat planning (sub-codes: positive and negative), technological, economic, institutional, and behavioural conditions, each with sub-codes on specific subtopics, actors, and participation.

4.5 Results and Discussion

In the first part of the analysis (Section 4.5.1), I identify path dependencies in low-temperature heat supply that could be interrupted in Baden-Württemberg with the help of municipal heat planning, especially with regard to NG distribution infrastructure. All of them are institutional in nature. However, not all path dependencies can be addressed by heat planning alone and can thus lead to a lock-in of

[103] The following quotes from the actors are my own translation.

NG. I discuss these persisting path dependencies in the second part of the analysis (Section 4.5.2) which is subdivided into institutional, infrastructural, behavioural, and discursive path dependencies.

4.5.1 Path dependencies tackled by communal heat planning

All stakeholders interviewed rated the municipal heat planning positively and as a first important step to initiate long-term heat planning, even if the design has some weaknesses. Through improvements in the design of the communal heat planning the potential to overcome path dependencies could still be strengthened. I also address this aspect in the analysis.

Heat planning overcomes planning deficit and creates investment security

Optimised investment planning for the heat transition requires a coordinated approach based on long-term planning supported by the relevant data (MU, RAO, NO, C, BGT). Communal heat planning creates the conditions for this and makes the strategic planning and temporal coordination of the transition possible in the first place (MU). For example, the communal heat planning allows DNOs to make targeted investments in maintenance only in areas where networks will have to be operated for a longer period (under the current regulatory system (see Section 4.5.2.1), such strategic long-term planning is the only significant control option DNOs have to interrupt NG path dependency (RAO, MM, NO)). The development of risk-determining factors that indicate priority areas for the decommissioning of the NG network could be of help for DNOs and planners. Possible factors in an area could be: a) the advanced age of gas boilers (MM, C), b) the age of the network (MM), c) high upcoming investments in maintenance (RAO), d) prospectively declining gas consumption due to neighbourhood modernisation (RAO), e) existing large waste heat sources or anchor customers for DH (MM, RAO, C), f) upcoming civil engineering measures which might favour the laying of heating networks (RAO), g) low connection density to the NG network (C).

Communal heat planning also provides planning security and decision support for property owners. For example, replacing a NG heating system with a renewable alternative currently requires an educated guess as to what can (still) be economically operated over the next 10 or even 15 years, and this unsettles many consumers. Especially when the vast investment requirements are taken into account (e.g. conversion of the heating system, replacement of radiators, facade insulation), such an estimate is hardly reasonable for the individual property owner from a consumer protection point of view. The priority areas defined in the communal heat planning give homeowners a basis for such an investment decision (RAO). At the same time, municipalities can proactively approach undecided owners and promote renewable technologies (MM, RAO).

Shaping the heat transition is made possible by access to previously non-public data

Paragraph E of the Climate Protection Act authorises municipalities to comprehensively collect data (State Parliament of Baden-Württemberg 2021). These possibilities were not previously available but constitute an important first step for the creation of resilient heat plans (C, SA). Even though access to data has been simplified, several stakeholders reported that they had difficulties in obtaining data from DNOs (e.g. information on the economic competitiveness of networks, flow rate, value, and age) (RAO, C). Especially when the operators are private companies (RAO). In some cases, the operators themselves did not have the data in detail (C). At this point, more clarity could be created as to which data regarding the NG distribution networks are needed for communal heat planning and the corresponding companies could be obligated to collect and pass on this data.

In addition, the data is currently available in very different formats and measurement units. In the future, a uniform collection of data could significantly simplify the planning process (MM, C, RAO). So far, detailed data may only be used for heat planning and must be deleted afterwards. This makes both updating and implementing the heat plans more difficult because the data is then only available in aggregated form (C, RAO). In a revision of the law, specifications for data collection could be made, and the possibility of storing disaggregated data beyond the planning process could be considered.

Building knowledge and personnel capacities at the municipal level help to institutionalise the heat transition

Before the Climate Protection Act was passed, most municipalities did not feel responsible for the heat transition and accordingly did not have the personnel capacity or expertise to do so. Municipal heat planning creates responsibilities for the transition and thus provides the initial impulse to establish appropriate structures, personnel and expertise on the ground (MM).

In Baden-Württemberg, information has been provided by the State Energy Agency in order to build up the appropriate professional competencies in the municipalities (RAO, NO). In addition, regional advisory offices have been set up throughout the State to support the municipalities. However, the compensation payments from the state for conducting the heat plan do not cover the costs for building up personnel capacities (MM, RAO, MU, SA). This can lead not only to the problem of a lack of continuity in heat planning and implementation, but also to knowledge asymmetries compared to other stakeholders (RAO, MM), such as network operators, and thus to insufficient representation of municipal interests in the process.

Knowledge deficits in municipalities regarding environmental aspects of NG as well techno-economic aspects of hydrogen (e.g. availability, technical feasibility, costs) can also lead to significant stranded assets (RAO, MM). For example, planners or municipal utilities preparing to decommission NG distribution networks might expect political headwinds from city or town councils who often continue to view NG as an easily manageable and clean energy source (SA), while the continued use of NG networks, possibly also with hydrogen, could be met with more approval (RAO).

Quote RAO: "*These are interested newspaper readers. They get to know that hydrogen is under discussion. And I think it is massively underestimated how much influence this normal everyday political debate has on the decision-makers. They have neither the time nor the expertise to deal with these things. They don't have the input and they don't know what the technical possibilities are and how much hydrogen will be available for heating buildings.*"

Participation of relevant stakeholders in heat planning lowers resistance for heat transition

The opportunity to involve relevant local stakeholders is an important advantage of the communal heat planning. On the one hand, the interests of different stakeholders can be taken into account, and on the other hand understanding for certain developments can be promoted at an early stage. A lack of participation does not necessarily have a negative impact on the preparation of the communal heat plan. However, implementation can be made much more difficult if central actors resist the transition because they do not see their interests sufficiently considered or cannot understand certain developments, such as the decommissioning of the NG network and the subsequent need to have one's own heating system replaced (MM, SA, BT). The use of regulatory law alone cannot counter this problem (MU, RAO).

In the formulation of the communal heat planning guidelines in Baden-Württemberg, experienced municipalities and planning offices were involved. Furthermore, the expertise of various research institutes and professional associations was obtained for the technology catalogue[104] (SA). Despite these initial inclusive approaches, it is highly welcomed but not obligatory to involve central stakeholders (e.g. municipal utilities, real estate owners, tenants, craftsmen, private operators of infrastructures) in the planning process, and accordingly no additional financial means are foreseen for this (MU, C). Public participation, which is legally anchored in other projects (such as traffic management planning) is not required and, in many cases, not implemented, which is why civil society actors feel the process lacks transparency and report a sense of frustration (RAO, CS).For this reason, there would also be potential for improvement at this point. Lörrach could serve here as an example of best practice. Various municipalities in the district carry out the heat plan together and developed structures to allow for stakeholder participation.[105]

4.5.2 Persisting path dependencies

Although the municipalities are obliged to prepare a communal heat plan, there is no obligation to implement it in part because they would lack the means to tackle path dependencies. In addition to the institutional, infrastructural/economic, behavioural and discursive path dependencies identified in this section, technical barriers could also play a role. However, none of the interviewees, although specifically asked about it, mentioned any technical barriers related to decommissioning NG networks. Possible technical challenges in the provision of renewable heat or problems in the renovation of buildings were not discussed in the interviews.

4.5.2.1 Institutional path dependencies

At the municipal level, some legal options such as compulsory connection and the use of a heat network or the prohibition of specific heating systems (“Verbrennungsverbot”) exist to limit the further expansion or use of NG for building heat. However, the necessary competencies to interrupt path dependencies at the institutional level lie with the federal government.

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[104] Following Denmark's example, a technology catalogue is published in addition to the planning guidelines. The catalogue appears online and is regularly updated to reflect the latest technological developments (SA). The catalogue helps make the plans of the individual municipalities comparable (SA). For planners, the catalogue also provides a solid reference, especially when it comes to controversial developments such as hydrogen (C). And for municipalities, it serves as a control tool to check whether contractors have carried out planning with realistic assumptions (SA). So far, there is no obligation to apply this catalogue (SA). The catalogue is still being compiled and is expected to be published for the first time in spring 2022.

[105] The participation process is made up of three bodies: 1. The advisory board brings together a heterogeneous stakeholder group (e.g. state energy agency, representatives from the municipalities, energy cooperatives, private energy utilities, municipal utilities, associations of the craftsman and chimney sweeps, industry). 2. The expert group consists only of practitioners. 3. The steering committee with representatives from all municipalities. The establishment of a fourth group with property owners is still under discussion.

Existing regulation fosters an expansion of the network

The regulatory system in Germany essentially follows the “revenue-cap” approach (Then, Spalthoff, et al. 2020, 5). The DNO receives a fixed return on capital invested for the secure and *needs-based* expansion of the networks (EnWG 2005, section 11). To avoid any unnecessary expansion, the DNOs are regulated by the federal regulator (Bundesnetzagentur, Federal Network Agency) or the respective state regulatory authorities. Based on an efficiency comparison between the DNOs, the regulator sets the profit cap for the operators, which is then passed on to the gas customers through network charges (AregV 2009). Accordingly, the only way for DNOs to make profit is through the expansion of the network (BT). On average, more than 1 billion euros per year was invested in the NG distribution networks in Germany between 2009 and 2020 (BNetzA and BKartA 2021, 365).

The operator is obliged to provide network access[106] wherever a network exists (EnWG 2005, sections 17, 18, and 20) even if the municipality has not planned for a NG network in this area for other reasons (e.g. the communal heat planning). This is because there is no political criterion for *needs-based expansion* for distribution networks (unlike transmission networks, where the energy policy goals of the federal government must be considered). The only criterion that the regulation provides as grounds for an operator to deny a grid connection is proof that it is not technically or economically feasible to do so. Both are nearly impossible to prove (LE).

Even if the municipality owns the gas network, it cannot use the heat plan as a criterion for denying network expansion where someone proclaims a grid connection, since it is equally bound by the regulation. Especially since there is no implementation obligation for the municipal heat plan (LE). Therefore, the remunicipalisation of the networks for the heat transition also not a possible solution either and only leads to the municipalities having to bear the loss of value of the networks (SA).

Quote NO: “*Simply because of this supply obligation, simply from the rules of the game that the federal regulatory agency prescribes, I see no possibility at all, as of today, that we would carry out noticeable decommissioning at the end of the twenties. We might not do any more expansion, yes, but real decommissioning is not possible at all*.”

Apart from the fact that the existing regulation fosters the expansion of the network, it brings with it further negative effects for the heat transition:

While the distribution grids must continue to be operated as long as even one single gas consumer is connected, in perspective, more and more customers will switch to a renewable heat supply. This will increase the grid fees for the few remaining customers, which in turn could lead to further disconnections (Engelmann et al. 2021; Bürger et al. 2021; Wachsmuth et al. 2019; see also Section 2.3). This development could reduce the acceptance of the transition, for example, among tenants who have no influence over their heating system but would have to bear the rising network tariffs.

Furthermore, in pioneering municipalities that offer alternatives to NG at an early stage, the DNOs will suffer additional economic losses. They will perform worse in the efficiency comparison (due to the loss

[106] In Germany, around 275,000 buildings have been converted from oil to NG for heating in the last ten years (in around 17,000 buildings from oil to DH). Oil is still used to heat 2.7 million residential buildings (BDEW 2019).

of customers but the need to continue to operate networks) and will therefore not be allowed to charge higher network fees despite fewer users (NO). In particular for municipalities that own the networks themselves or are shareholders in municipal utilities that operate the networks, this is an obstacle to pushing ahead quickly with the NG phase-out.

According to Article 35 of the building code (Ministerium der Justiz 2017), previously decommissioned pipelines may not remain in the ground, but must be removed (SA), which represents an additional cost for operators. From a technical point of view, it would be possible to leave them in the ground and, if necessary, fill them with nitrogen for preservation (NO) (Wachsmuth et al. 2019). A legal amendment would be needed here too.

Concessions do not allow for a reduction of the concession area or consideration of non-economic criteria when awarding them

In Germany, the rights to the NG distribution network are awarded to an operator by means of a concession contract for a limited period (maximum 20 years) (EnWG 2018, §46). At the end of this period, the concession is tendered again. Concession agreements clearly regulate what may or must happen to the network. So far, they do not provide for decommissioning (RAO). The concession area basically covers the entire municipality and a reduction in size (e.g. on the basis of the communal heat plan) is not possible (MM, SA). The concession award is based solely on economic criteria. Criteria such as climate protection or the link to the communal heat plan are not permissible (RAO, LE).

Existing regulation does not provide for the decommissioning of the gas networks

DNOs must adhere to a depreciation period of 45 to 55 years for their networks. The decommissioning of distribution networks before the depreciation period leads to “stranded costs” and requires corresponding value adjustments on the part of the DNOs (Bürger et al. 2021). In Germany, 47 percent of the pipelines were built or renewed between 1990 and 2014 and would thus only be partially depreciated by 2040 (assuming a depreciation period of 55 years) (Dietzsch et al. 2016). It is still unclear how these stranded costs should be dealt with in the event of decommissioned grids.[107]

4.5.2.2 Infrastructural and economic path dependencies

In 2020, there were 40,000 employees in the gas industry in Germany (AG Energiebilanzen e.V. 2021, 16). However, the topic of jobs in the NG industry did not play a role for the interviewed stakeholders. Unlike the coal industry, these are not regionally concentrated. In addition, all stakeholder groups emphasised the existing and worsening shortage of skilled workers and stressed that this must be countered with comprehensive training and development initiatives.

[107] In principle, two variants, or a mixture of both, are conceivable (LE): 1) Partial value depreciation: The residual value of the network is depreciated at the time of decommissioning. In this variant, the remaining customers are charged. 2) Shortening of depreciation periods: Here, it is necessary to know how long the relevant network can still be operated (e.g. through a clear exit date or a binding communal heat plan). Accordingly, the depreciation period is shortened, and the costs incurred are spread over more customers.

Municipalities rely on revenues from municipal utilities or taxes and fees from private utilities and DNOs to finance public services

In many municipalities, the (profitable) operation of gas networks and the trading of NG is handled not only by private suppliers but also by municipal utilities which also perform other (unprofitable) tasks of public services[108] (e.g. public transport). If the revenues from NG sales and network operation were to decline, these services could no longer be financed by the municipal utilities (MM). The decline would cause additional economic problems in municipalities that recently remunicipalised the NG network and plan to pay the debts through revenues stemming from the operation. If, in turn, the NG network is owned by a private operator, municipal budgets would lose revenue from concession fees if (parts of) the network were decommissioned. Concession fees are a secure and “business-cycle-independent” source of income, which is particularly important for smaller municipalities (RAO, SA). New concepts are needed for municipalities and municipal utilities to generate revenue in the future. So far, however, no rethinking has taken place, and the municipalities continue to count on the profits from the municipal utilities, and the municipal utilities lack personnel with the appropriate expertise to develop new promising business models (MM, MU, BO, C, SA).

This situation is an obstacle for projects that would make sense from an energy point of view, but cannot generate high profits. For example, to construct a DH network municipal utilities usually have to set a relatively high rate of return (5-10 percent), to cross-finance other activities (RAO, SA, MU, CS).[109] Furthermore, municipalities making a major, credit-financed investment in a DH network are subjected to a debt embargo by the district, as investments in DH networks are not considered assets (in contrast to NG networks) (RAO, SA).

Quote (RAO): “*The debts for such an asset (district heating network, author's note), which at some point will pay off like a heating network, are valued in the same way as if I were to make a golden crosswalk now. So it doesn't matter if it's worth it. Debts have a negative connotation, and municipalities are not allowed to run up such high debts*.”

Business models of the utilities are not aligned for the heat transition

Up to now, the business models of municipal utilities (as well as private utilities) rely on NG supply in the heat sector. The heat transition requires utilities to develop new competencies, strategies and business models in order to be able to implement the phase-out of NG supply as well as the use of new technologies (MM). For example, municipal utilities employ three times as many people in gas supply than in grid-bound heat supply (Bruckner et al. 2017). To this end, retraining can take place within the utility to shift personnel capacities from NG network expansion to DH, where the existing shortage of personnel will increase (MU). With decentralised solutions, one revenue path is the sale of electricity, the demand for which will presumably increase (MU). The sale of heat pumps or contracting models

[108] More than 80 percent of the municipal utilities surveyed distributed profits generated in 2014 to their shareholders. The average payout ratio was more than 50 percent of the annual net profit (Bruckner et al. 2017).

[109] In Denmark, municipal utilities are not allowed to make any profits at all (Chittum and Østergaard 2014).

would be a paradigm shift, requiring the development of completely different competencies, and is associated with many economic uncertainties (MM).

The adaptation of business models can cause conflicts of objectives (Hensel 2013). For example, the expansion of DH networks is difficult if a NG network already exists in a supply area. If the NG network and the DH network belong to the same operator, the operator would worsen the efficiency rating in the benchmarking of its gas network in addition to creating competition for the utility's own infrastructure (RAO, NO). If the existing gas network belongs to another operator, the latter can attract customers with offers that are difficult to undercut (CS).

So far, the pressure on energy suppliers to tackle these extensive changes is still relatively low.

Quote MU: *"There are certain hurdles to overcome, from an economic point of view, with the heating networks as well as with the gas network. And we are still in the discovery phase. Municipal utilities tend to be a bit slow. I would say that we have been discussing this internally in the department for some time now. But it takes a relatively long time before something actually happens and there is pressure to act."*

4.5.2.3 Behavioral path dependencies

In the existing literature on carbon lock-ins, there has been little focus on lock-in mechanisms caused by habits, behaviour patterns, norms and values (Seto et al. 2016). However, interviewees from different stakeholder groups have highlighted these aspects. They stressed that the success of the heat transition depends strongly on understanding behavioural path dependencies and finding effective strategies to overcome them, because the heat transition depends on many individual decisions from homeowners and will entail changes in the private sphere (the home) and adjustments in the everyday working lives of installers and traders, for example.

Insufficiently understood and complex interplay of different factors influencing homeowners

The willingness of real estate owners to invest in the heat transition is influenced by various factors. For instance, people's mentality: In some places, it is considered important to own the heating system (for a sense of independence or security), while in other regions, leasing a heating system is much more widely accepted (MU). The same applies to the use of grid-connected heat, which is very widespread in urban areas but is met with scepticism in rural areas (MU). Confidence in new technologies also influences the decision. Many customers are risk-averse and, when in doubt, opt for the system they already know. Another factor that should not be underestimated is the personal conviction of a consumer or his/her social environment (e.g. strong opinions among acquaintances) (NO). Of course, subsidy policies and costs as well as infrastructural possibilities also play a role in the choice of heating system (MU). A deeper understanding of all these factors is needed to develop an appropriate strategy for taking the heat transition to the mainstream.

The existing expertise of consultants, installers, etc., is not compatible with the heat transition

Energy consultants, chimney sweeps, and installation technicians want to give their customers good advice and, when it comes to replacing a heating system, may prefer to recommend the old familiar systems (C). For the implementation of the heat transition, these actors need to be willing to stay up to date with the latest technological state of the art. In addition to suitable training and continued education measures, authorities should seek dialogue early on in order to counter possible fears and concerns (C, MU). Furthermore, an understanding of the necessity and advantages of new systems must be created in retail, alongside possible incentives to advise customers in this regard. So far, the effort involved in explaining a new system to a customer instead of simply selling a gas heating system does not pay off for the retailor (RAO).

4.5.2.4 Discursive path dependencies

Low public acceptance for NG exit due to general perception of NG as a transition fuel

Public acceptance is a prerequisite for decisive political action to phase out NG. Furthermore, the heat transition depends on the willingness of real estate owners to invest in the heat transition themselves (C, SA). However, both at the EU (e.g. taxonomy) and at the federal level (e.g. coalition agreement), NG is deemed to be a transition fuel and, as a result, new NG infrastructure will still be supported with state funds. Therefore, it is not surprising that local councils, municipal utilities, consumers, or the traders are unaware that the role of NG will change, and that the corresponding infrastructure will have to be decommissioned sooner than later (RAO, CS). Accordingly, it is ultimately difficult to plan for the decommissioning of NG distribution networks when preparing the communal heat plan and to obtain approval for this in the municipal council (RAO). So far, planners can theoretically avoid such a conflict by, for example, assuming the increased use of hydrogen or biogas and thus the continued operation of the networks (RAO, CS).

Discourse on the role of hydrogen delays heat transition

Some actors repeatedly introduce the central role of hydrogen in decentralised building heat supply to the discourse[110] and put forward the expectation that the distribution networks could continue to be used in full or at least to a large extent (LE). However, investments in the conversion or new construction of networks may be stranded or lock-in NG because the operation of larger parts of the gas distribution network by substituting NG is not likely (Meyer, Herkel, and Kost 2021) for various reasons (ecologically questionable, not beneficial to the system, availability, uneconomical (MM, MU, NO, SA)).

Moreover, the widespread use of hydrogen in building heating would require a much greater logistical, technical and financial effort than is often claimed. It requires the construction of a hydrogen network parallel to the existing NG network or an extensive conversion of the NG network (see e.g. ACER 2021). At the same time, the replacement of all consumer appliances with NG- and hydrogen-compatible models would have to be driven forward. Irrespective of the availability of the required hydrogen or its economic viability, the question arises as to whether planning such a comprehensive conversion of the network and appliances would be possible within a reasonable period of time (Wachsmuth et al. 2019). The complexity of such an undertaking can be estimated on the basis of experience in Germany with

[110] E.ON. 2020. "„Vom Großen ins Kleine“: Von der Energiewende im Wärmesektor zum „Digital Energy Twin“ der Stadt Essen." Accessed February 18, 2023. https://www.eon.com/de/ueber-uns/politischer-dialog/energiewende-mit-gruenem-gas.html. VKU NRW, BDEW NRW, and DVGW NRW. 2022. "Wasserstoff in den Wärmemarkt – Verbände fordern Ergänzung der Wasserstoff Roadmap NRW." Accessed February 21, 2022. https://www.dvgw.de/der-dvgw/aktuelles/presse/presseinformationen/dvgw-presseinformation-vom-19012022-wasserstoff-in-den-waermemarkt.

the L-H gas conversion.[111] A quarter of gas customers are expected to be converted within twelve years at considerable personnel expense. In comparison, the conversion to hydrogen would be even more technically demanding, and implementation on a nationwide basis by 2040 or 2045 is considered unrealistic (LE).

The guideline for communal heat planning states that an extensive use of hydrogen is not considered a solution and, if too many municipalities plan to use hydrogen, they will be obliged to revise their planning (SA) (Klimaschutz- und Energieagentur Baden-Württemberg GmbH 2020, 76). However, at both the state and federal level, there is a lack of clear specifications or exclusion criteria that all stakeholders can refer to.

4.6 Conclusion

The EU has a large NG distribution network covering most EU countries, many of which rely heavily on NG for residential heating. So far, no political strategy exists, neither at the EU level nor in individual countries, for how to implement a downsizing of the NG distribution network in the context of the heat transition (Sahni et al. 2017). This deficiency should be quickly addressed to interrupt the path dependency originating from the NG distribution network and to prevent the lock-in of NG. In this paper, I have analysed whether communal heat planning, as implemented in the German state of Baden-Württemberg, is suitable approach in this regard. The findings from this case are also helpful for other EU countries in developing strategies to address the heat transition and the related decommissioning (of parts) of the distribution network.

The analysis shows that communal heat planning can help overcome some institutional path dependencies by:

- Creating responsibility for heat planning in the municipalities and thus helping overcome the planning deficit in the heat transition. In this way, planning security is created for the expansion and decommissioning of large infrastructures.
- Creating access to necessary data, which allows municipalities to shape the heat transition. With regard to the NG grid planning, it is helpful to identify relevant data (e.g. age, condition, throughput, value) and require operators to collect and provide this information to the municipalities.
- Supporting the development of personnel capacities and knowledge bases for the heat transition at the municipal level and thus also an adequate level of information on the climate impact of natural gas and the availability and technological feasibility of hydrogen. This can prevent stranded assets or the lock-in of NG. Adequate financial resources for capacity building on municipal level should be made available.

[111] Parts of the German gas market are supplied with low-calorific NG (L-gas). This gas comes exclusively from German and Dutch production, which has declined considerably. Gas from other import sources is high calorific (H-gas). The two groups must be transported in separate systems because of their different properties. In order for customers to be able to use H-gas instead of L-gas in the future, distribution infrastructure as well as all NG-powered end devices must be adapted.

- Enabling the involvement of local stakeholders, thus ensuring the acceptance and practicability of the heat transition. Both funds and expertise must be made available for setting up participative structures.

The municipal heat planning process is suitable for drawing stakeholders' attention to the topic and for initiating the discussion about phasing out NG in low-temperature heat supply as well as for identifying alternatives suited to the local context. However, it is not a sufficient instrument for overcoming all major institutional, infrastructural, behavioural and discursive path dependencies through the NG distribution network and allowing for the actual implementation of the heat plans:

- Existing regulation fosters an expansion of the network even in situations where municipal heat planning does not anticipate an expansion or even plan for the decommissioning of the NG networks.
- Concessions do not allow for a reduction of the concession area or the consideration of non-economic criteria, such as the communal heat plan, when they are awarded.
- Existing regulation does not provide for the decommissioning of the gas networks, which is why frontrunner utilities that offer alternatives to NG at an early stage suffer twofold economic losses.
- To finance public services, municipalities rely on revenues from municipal utilities or taxes and fees from private utilities and DNOs. A decline in NG consumption would endanger the provision of services such as public transport. This dependency can lead to municipalities being extremely critical of a phase-out of NG.
- The utilities' business models are not aligned for the heat transition and, so far, there is hardly any political pressure to rethink existing business models and build up the corresponding competencies, which could lead to a possible lack of qualified staff.
- The complex interplay of different factors influencing homeowners in their investment decisions are insufficiently understood. However, a phase-out of NG is not feasible without the willingness of property owners to modernise their homes and develop confidence in new technologies.
- The existing expertise of consultants and installers, for example, is not compatible with the heat transition, which is one reason why familiar systems such as NG heating systems continue to be sold.
- The low public acceptance for NG exit due to the general perception of NG as a transition fuel makes it difficult to communicate the need for a phase-out of NG in low-temperature heat.
- Discourses on the role of hydrogen delay heat transition and can lead to stranded assets in hydrogen infrastructure or the conversion of NG infrastructure.

In order to interrupt path dependency and bring the heat transition from planning to implementation, the appropriate institutional, infrastructural, behavioural and also discursive framework conditions must be created. These underlying conditions differ depending on the individual EU country. However, the example of Baden-Württemberg offers initial insights into which political instruments can contribute to overcoming path dependency (see Figure 12).

Federal Government

- Create a legal framework for disinvestment in the NG network (e.g. based on communal heat plans)
- Elaborate a regulation that determines how the loss in value due to shortened operating times of distribution networks is to be depreciated in the future
- Adapt legal framework ensuring that climate protection targets serve as a basis for operation and allowing for integrated infrastructure planning
- Create higher investment security (e.g. clear phase-out dates)

In Cooperation

- Develop a clear guideline for hydrogen and NG use in low-temperature heat and a corresponding communication strategy
- Develop indicators for the decommissioning of the NG network
- Create clear responsibilities and push for inter-ministerial cooperation to address the shortage of skilled workers and materials
- Minimise risks for consumers in the use of new, climate-friendly technologies
- Initiate information campaign targeting homeowners on alternatives to NG for heating
- Develop a better understanding of consumer preferences (in cooperation with utilities)
- Address the fears and concerns of stakeholder groups (e.g. chimney sweeps) regarding their future role in the heating supply by outlining perspectives
- Support utilities with capacity building for the heat transition and development of new business strategies

State Government

- Investments in the heat transition must not be interpreted negatively for the municipalities
- Address the training needs of installers and energy advisors

Municipalities

- Use already existing legal possibilities to implement the heat plan
- Build up expertise for the heat transition and consider an inter-municipal approach to bundle capacities
- Address and involve all relevant stakeholders in the municipal heat planning process (especially those that might be negatively affected in order to show them perspectives)
- Analyse the effects of a phase-out of NG supply and the decommissioning of the NG distribution network on the financing of municipal services and develop a corresponding adaptation strategy

Figure 12: Necessary adjustments to the institutional, infrastructural/economic, behavioral and discursive conditions for the implementation of the heat transition.

Source: Own depiction.

The findings of the study are limited by the fact that the planning process in Baden-Württemberg was still in its early stages when the interviews were conducted. An evaluation of already completed heat plans could therefore not be included. Furthermore, this paper focuses on the NG infrastructure; other important infrastructural aspects of the heat transition were not examined and could serve as the focus of future research. To analyse the transferability of this paper’s findings to other contexts could also be the subject of future research. A comparative study of different approaches to municipal heat planning – for example, in Germany, the Netherlands and Austria – could also yield interesting results. Viewing the heat transition from the gender perspective could address questions such as how to inspire more women to take part in the heat transition, in energy consulting or as professionals, for example, and what women's specific needs are in this transition?

This analysis shows that all kinds of strong path dependencies caused by the NG distribution network can potentially hinder a heat transition and lock-in NG. Municipal heat planning, supported by appropriate policy measures on all political levels, is a suitable steering instrument for developing and implementing a long-term strategy for the decarbonisation of low-temperature heat and thus overcoming these path dependencies.

5 Chapter 5: Overcoming political stalemates: The German stakeholder commission on phasing out coal

5.1 Introduction

To meet the international 1.5°C (or well-below 2°C) climate target, a substantial decline in global coal consumption is needed by 2030 (IPCC 2018; 2022).[112] However, despite the reduction of coal consumption in some countries, global consumption has remained relatively flat over the last decade (IEA 2020a). At the UN Climate Change Conference in Glasgow (2021) the international community has agreed to phase down global coal (UNFCCC 2021), renewing impetus to address a timely transition away from coal. In individual countries, societal and political pressure to deliver on climate mitigation and to phase out coal is growing (Blondeel, Van de Graaf, and Haesebrouck 2020; Rinscheid and Wüstenhagen 2019). However, in other countries, the future of coal remains highly contested, due to economic dependencies on coal, fear of job losses, and incumbent actors profiting from the status quo (Diluiso et al. 2021; Jakob et al. 2020; Jewell et al. 2019; Newell 2018; Ohlendorf, Jakob, and Steckel 2022). This can lead to stalemate situations between opposing stakeholders, with the incumbent system increasingly becoming under pressure, however, still able to prevent or delay a transition away from fossil fuels, such as coal (Brisbois and Loë 2016; Leach, Scoones, and Stirling 2010; Sabatier and Weible 2007; Seto et al. 2016).[113] A few countries, such as Canada, Chile, and several European countries, have announced a coal phase-out in recent years.[114] However, in most of these countries, coal only played a subordinate role in the energy system and in terms of employment at the time of the decision (Blondeel, Van de Graaf, and Haesebrouck 2020; IEA 2019a; Jewell et al. 2019).

A notable difference is Germany, the world's largest lignite producer and consumer, with high economic and social dependence on coal in some of its coal mining regions (Jewell et al. 2019; Oei, Brauers, and Herpich 2020). Based on the recommendations of a stakeholder commission, the "Commission on Growth, Structural Change and Employment", hereinafter referred to as the (Coal) Commission, Germany determined to phase out coal consumption and production the latest by 2038, and to implement structural change measures for affected regions (Gürtler, Löw Beer, and Herberg 2021). The agreement of the Coal Commission received wide attention and was celebrated by many as a milestone to phase out coal, after several political attempts to reduce Germany's use of coal in previous years had failed due to overwhelming resistance by supporters of a continued use of coal, within and outside of governing parties (Furnaro 2022; Hermwille and Kiyar 2022). Particularly, the coal industry and related unions, energy-intensive industries, as well as politicians in coal mining regions tried to stall any policy

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[113] According to Sabatier and Weible (Sabatier and Weible 2007, 206) a "policy stalemate" describes "a situation in which all parties to the dispute view a continuation of the status quo as unacceptable". They consider a stalemate situation to be a prerequisite to successful negotiations because "individuals satisfied with the status quo have little incentive to give up anything in negotiations (…)."

[114] Europe Beyond Coal. n.d. "Europe's Coal Exit - Overview of National Coal Phase out Commitments." Accessed July 14, 2022. https://beyond-coal.eu/europes-coal-exit/. Ritchie, Hannah. 2021. "When Will Countries Phase out Coal Power?" Accessed July 14, 2022. https://ourworldindata.org/coal-phase-out.

to reduce coal use in Germany (Bang, Rosendahl, and Böhringer 2022; Hermwille and Kiyar 2022; Kalt 2021; Leipprand and Flachsland 2018).

Collaborative (or participatory) governance (CG) approaches, such as the Coal Commission, are considered to offer possibilities to overcome stalemate situations and promote consensus-oriented decisions that exceed lowest common denominator compromises in previously highly contested issues (Emerson and Nabatchi 2015; Sabatier and Weible 2007). However, lack of win-win scenarios, strong belief heterogeneity, or power imbalances among participants can limit the success of CG (Dutterer and Margerum 2015; Brisbois and Loë 2016). Considering conflicts over the future of coal, scholars argue that just transition objectives and stakeholder involvement could contribute to achieve timely and equitable coal phase-outs (Diluiso et al. 2021; Jakob et al. 2020; Muttitt and Kartha 2020).

In the Coal Commission, representatives of different interest groups were supposed to develop recommendations for a phase-out pathway and closing date for coal, and measures to support structural change in affected regions (BMWi 2019d). Due to a history of intensive conflicts and highly diverging objectives among stakeholders, many questioned beforehand if the Coal Commission could resolve the issues at hand, while others criticized it for being not ambitious enough in its climate objectives (Grothus and Setton 2020; Gürtler, Löw Beer, and Herberg 2021; Hermwille and Kiyar 2022). However, in the end the Commission achieved to develop and pass recommendations supported by all influential actors in the related German context, achieving a high level of legitimacy for these recommendations and overcoming the previous stalemate situation (Gürtler, Löw Beer, and Herberg 2021; Praetorius et al. 2019).

In this paper, we assess how the stalemate situation in the German conflict over the future of coal was overcome, enabling the agreement on a coal phase-out in Germany. We focus on the process of the "Commission on Growth, Structural Change and Employment" and the question, how this Commission achieved to breach the previous stalemate situation and how the final recommendations were formed.

To assess this stakeholder commission process and the formation of its final recommendations, we apply the integrative framework for collaborative governance, introduced by Emerson et al. (2012). This framework enables the systematic and empirical assessment of CG processes. For the empirical analysis, we use semi-structured interviews conducted with 18 participants of the Coal Commission and qualitative content analysis (Gläser and Laudel 2010a). Our findings may help to further the debate on politics of phasing out coal and achieving just transitions, and contested sustainability transitions in general. In particular, our findings may inform similar stakeholder commission processes in other countries or of other unresolved issues, such as the future of fossil fuel consuming industries.

This paper is structured as follows: Section 5.2 presents the integrative framework for collaborative governance and methods applied. Section 5.3 presents the analysis of the Commission's system context, drivers, and regime formation. In Section 5.4, we present the findings on the dynamics of the Commission. We discuss our findings in Section 5.5 and in Section 5.6 follows our conclusion.

5.2 Theoretical approach and methodology

Collaborative (or participatory) governance (CG) approaches are receiving increased attention as a means to address resource and environmental conflicts (Ansell and Gash 2007; Emerson, Nabatchi, and Balogh 2012; Newig et al. 2018a). CG can promote consensus-oriented decisions that exceed lowest common denominator compromises in previously highly contested issues (Emerson and Nabatchi 2015; Innes and Booher 1999; Krick 2015; 2013; Sabatier and Weible 2007), and it can help to “neutralize veto positions” (Krick 2013, 28). By including expert knowledge, public interests, and consensus-building in decision-making, CG can increase public acceptance and support for certain policies (Krick 2013; Boswell 2009; Siefken 2016). However, collaboration can also be limited by a lack of win-win scenarios, strong belief heterogeneity, and the high complexity of debated issues. Other potential limitations include power imbalances among participants, and external pressures (Dutterer and Margerum 2015; Brisbois and Loë 2016; 2017; Krick 2013). Some also criticize CG processes as means to dilute accountability and political responsibility by governments, and the desire to avoid having to make critical decisions (Hanemann and Dyckman 2009; Kallis, Kiparsky, and Norgaard 2009; Krick 2015; Siefken 2016). Evidence that collaborative and other participatory governance processes could improve environmental standards of derived policy outcomes remains scarce (Jager et al. 2020). The integrative framework for collaborative governance by Emerson et al. (2012) builds on a wide range of literature for the analysis of different forms of collaboration and collaborative processes (e.g. Ansell and Gash 2007; Innes and Booher 1999), and has been widely used to assess collaborative (governance) processes (Emerson and Nabatchi 2015). We use the framework to structure our analysis of the Coal Commission and the decision-making process of its members.

5.2.1 Integrative framework for collaborative governance

Figure 13 depicts the integrative framework for collaborative governance as three nested layers comprising the outer *system context* and the *collaborative governance regime* (CGR, which contains the *collaboration dynamics* and *actions*.

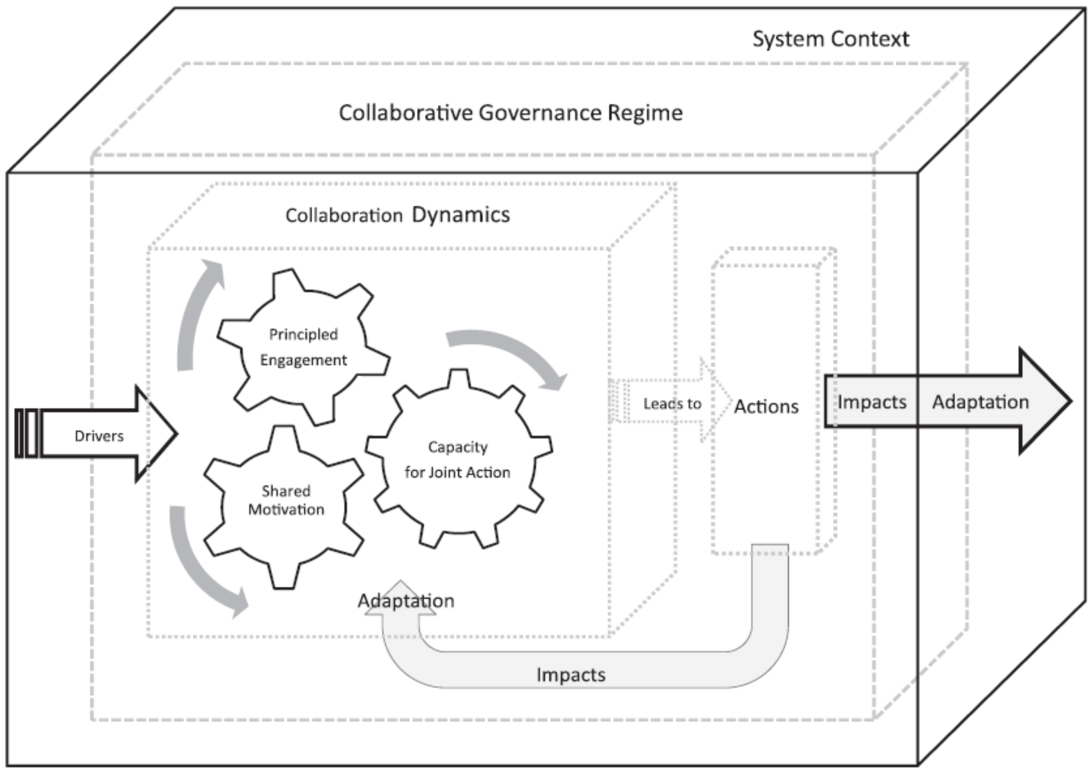

Figure 13: The integrative framework for collaborative governance.

Source: Emerson et al. (2012, 6).

The *system context* includes the "political, legal, socioeconomic, environmental and other influences that affect and are affected by the CGR" (Emerson, Nabatchi, and Balogh 2012, 5). *Drivers* from the system context form and influence the direction of a CGR. This can include, in the case of externally directed CGRs (Emerson and Nabatchi 2015, chap. 8), the formulation of a mandate and the selection of participants. Emerson and Nabatchi (2015, 44) posit that the following four drivers are necessary to initiate a CGR and motivate relevant stakeholders to engage: "(1) uncertainty, (2) interdependence, (3) consequential incentives, and (4) initiating leadership". The studied CGR need to be seen in the historical and surrounding system context, and depend on drivers enabling and forming the CGR. We lay out the system context, drivers, and regime formation of the Coal Commission in Section 5.3.

The CGR encompasses the process of collaboration among the participants, as well as possible actions resulting from this collaboration, which can influence both, the ongoing collaboration, or the outer system. At the heart of the CGR are the collaboration dynamics, which can lead to collaborative actions or outputs, such as a piece of policy advice. They consist of ***principled engagement***, ***shared motivation***, and ***capacity for joint action***, which are in iterative interaction with each other (as depicted in Figure 13. Each collaboration dynamic comprises further elements:

Principled engagement comprises the elements ***discovery***, ***definition***, ***deliberation***, and ***determination***. The process of *discovery* aims to exchange information among participants, to gather new information, and to understand other participants' interests better. *Definition* is about aspects such as agreeing on the boundaries of the problem at hand. The *deliberation* process focuses on the problem-solving-oriented engagement of participants, and exchange among them, in contrast to a "mere bargaining or negotiation" situation (Newig et al. 2018a, 283). Finally, many *determinations* are needed to structure the actual collaborative process and to agree on joint outputs (Emerson and Nabatchi 2015).

S*hared motivation* comprises the elements ***trust**, **mutual understanding**, **internal legitimacy**,* and ***commitment***. The development of *trust* among participants is essential, enabling open exchange and providing the basis for *mutual understanding*, which "refers to the ability to comprehend and respect others' positions and interests, even when one might not agree with them" (Emerson and Nabatchi 2015, 66). Both of these elements are necessary to achieve *internal legitimacy*, which results in participants trusting in the process and its efficacy. Based on these elements, bonds evolve between the participants of shared *commitment*, "which enable participants to cross the organizational, sectoral, and/or jurisdictional boundaries that previously separated them and commit to a shared path" (Emerson, Nabatchi, and Balogh 2012, 14).

Capacity for joint action comprises the elements ***procedural and institutional arrangements, leadership**, **knowledge***, and ***resources***. *Procedural and institutional arrangements* comprise "formal and informal rules and protocols, institutional design, and other structural dimensions … [that] manage the repeated interactions of multiple participants over time" (Emerson and Nabatchi 2015, 69). *Leadership* can be essential in multiple forms, such as to facilitate the deliberation process, to resolve conflicts, or to reach joint decisions. Chairs should therefore be "neutral and skilled mediators" whose main tasks are to implement professional and working norms, to settle disputes between members, and to facilitate an equal say in discussions and decisions for all stakeholders (Sabatier and Weible 2007, 206). Shared *knowledge* about the issues at hand is one of the bases for collaboration. In this context, it can be understood as "social capital of shared information that has been weighed, processed, and integrated with the values and judgments of CGR participants" (Emerson and Nabatchi 2015, 72). *Resources*, such as time, institutional support, or personal connections, are rarely distributed equally among participants. To enable the fair and equal participation of all participants, it is necessary to address differences in resource endowments (Emerson and Nabatchi 2015; Newig et al. 2018a).

5.2.2 Data collection and analysis

We conducted 18 semi-structured expert interviews with members of the Coal Commission or their personal assistants, and the administrative office between November 2020 and March 2021 (chairs and administrative office (4); affected regions and communities (3); environmental associations (4); science (1); trade unions (2); business/industry (3); other (1)). Interviews with participants of the Commission process served to provide information on the inner working procedures, events, and interactions among participants. The interviews lasted between approx. 60 and 90 minutes and were conducted in German. Due to the COVID-19 pandemic, only one interview was conducted in person, all others via the video-conference tool Zoom.[115] The interviews were recorded and transcribed, resulting in 469 pages of interview data.

The interview guideline was developed on the basis of the integrative framework for collaborative governance and the prior to the interviews collected information on the German coal phase-out process.

[115] To ensure data protection, a university version of the software was used.

We used a qualitative content analysis approach (Gläser and Laudel 2010a) to process the interview data. We coded for 16 categories using the coding tool provided by Gläser and Laudel (2010a). Twelve categories were deducted from the twelve elements of collaboration dynamics (see Section 5.2.1). The categories from the framework were supplemented with the component "covered topics", to provide information on the priorities set in the work of the commission. We added inductively three categories on: 1) stakeholder networks within the Commission; 2) external influences on the Commission's work; 3) represented interests.

Additional information which we use in particular to describe the system context, the drivers and the formation of the Coal Commission is knowledge that was acquired during a research project from 2017-2022 on the German coal phase-out process, including numerous visits to all coal regions and regular meetings with all involved stakeholders, as well as through the insights of published reports, research articles, and documents from the Commission process.

5.3 The Coal Commission: System context, drivers, and regime formation

In Germany, so-called *expert commissions*[116] have a long tradition in the political system, providing advice on a specific topic on an ad hoc basis, or as institutionalized permanent councils (Krick 2013; Siefken 2016). The German Coal Commission is a typical example of such an expert commission with its mandate for policy formulation and its participants fulfilling the dual role of representatives or stakeholders, and at the same time of experts to their specific fields (Krick 2015). In the literature on CG this corresponds to an externally directed CGR (Emerson and Nabatchi 2015, chap. 8). As the integrative framework for collaborative governance describes, processes and developments within the studied CGR need to be seen in the historical and surrounding system context, and depend on drivers enabling and forming the CGR. In this section, we describe the historical developments and situation in Germany that led to the initiation of the Coal Commission and composes the system context in which the Commission was situated. This is followed by the drivers and incentives for participation, and the initial formation of the Commission.

Germany began to manage the reduction of hard coal (Oei, Brauers, and Herpich 2020) and lignite mining (Stognief et al. 2019) back in the 1960s. Reasons for the decline in mining were globalization (as imported coal was cheaper) and the later unification of Germany (since industries in the East were less cost effective than those in the West). Overall employment in the coal sector decreased from approximately 600,000 in the 1950s to less than 20,000 direct jobs in 2020. About 40% of German power production in 2017 was based on coal, down from more than 50% up to 2002.[117] In the late 2000s, however, incumbent utilities were still planning to expand coal-fired power generation capacities, and

[116] Siefken (2016) defines expert commissions in the German political system as „temporary appointed bodies (…) [whose members] for the most part come from the science community and interest groups – but not predominantly come from the parliament, government, and administration. They are tasked with providing subject-specific sound advice for policy plans, programs and measures" (own translation). Krick (2015) speaks of *hybrid advisory committees*, yet addressing the same bodies.

[117] Energy-Charts. 2021. "Annual net electricity generation in Germany." Accessed November 19, 2021. https://www.energy-charts.info.

expecting only a slow growth of renewables (Kungl and Geels 2018). Even in the early 2010s, a phase-out of coal power in Germany, parallel to the phase-out of nuclear power, was barely considered in the political debate (Furnaro 2022; Müller-Hansen et al. 2021; Selje 2022).

Towards the mid-2010s, pressure on the coal sector increased. Germany was expected to fall short of its 2020 climate targets, and, furthermore, the Paris Agreement made it seem inevitable that coal use would have to be reduced (Leipprand and Flachsland 2018). Several attempts to regulate the phase-out of coal failed due to resistance by the utilities and mining companies, which saw their business model threatened, and industry actors, which were worried about rising energy prices (Furnaro 2022). In 2016 the so-called 'safety standby' was implemented, which compensates a few selected lignite power plants for shutting down, but failed to initiate the complete phase-out of coal (DIW Berlin, Wuppertal Institut, and Ecologic Institut 2019). Decisions on the future of coal by the governing coalition of CDU/CSU and SPD was further complicated because "(…) the conflict lines did not seem to fall between but within the major political parties, at least the SPD and CDU" (Hermwille and Kiyar 2022, 29). Within the Federal Government, the Ministry for Economic Affairs had tended to argue in favor of the continued use of coal prior to the establishment of the Coal Commission, while the Ministry for the Environment had continuously argued in favor of a phase-out (Markard, Rinscheid, and Widdel 2021). In general, however, the government had been in favor of moderate rather than radical change (Leipprand and Flachsland 2018).

After being strictly against any measures for an early phase-out, a number of unions including Verdi started to consider options for a policy-induced coal phase-out. However, other trade unions, such as the IGBCE[118], continued to lobby for continued coal mining (Kalt 2021). Mining regions feared that they would face negative economic and social consequences due to job and tax revenue losses, and demanded financial support to manage the upcoming transition (Oei et al. 2020). On the other hand, local residents feared losing their homes due to the destruction of villages in the event of continued coal mining, and environmental NGOs called for a coal phase-out between 2025 and 2035 (Löw Beer et al. 2021).

Overall, this created a situation of high uncertainty over the future of coal in Germany, with none of the interest groups powerful enough to enforce a decision (Hermwille and Kiyar 2022; Leipprand and Flachsland 2018). The positions around the debate of coal were so divergent that a top-down decision from the government would have been very vulnerable to criticism from all sides, offering little to gain for political parties (Löw Beer et al. 2021; Liersch and Stegmaier 2022). As early as 2016, the Federal Government announced the establishment of some kind of commission in their Climate Protection Plan 2050.

In 2018, the then newly appointed Federal Government implemented the Coal Commission (Grothus and Setton 2020). The appointment resolution, or mandate, of the Commission set out the task to develop an "action program" by the end of 2018 (BMWi 2019d, 109). This action program was to ensure the achievement of the Climate Action Plan 2030 target for the energy sector (-61 to -62% emission reduction compared with 1990 levels), while supporting structural change and economic development

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[118] Industriegewerkschaft Bergbau, Chemie, Energie – Trade union for mining, chemicals and energy industries.

in affected regions, including the establishment of a fund from primarily federal resources for structural change. Furthermore, it was to include a pathway and a final date for the phase-out of coal-fired power generation. All these aspects were to be combined in a manner to achieve social acceptability and social cohesion (BMWi 2019d, 109).

The literature highlights the importance of incentives for cooperation and as a starting point for participation, which played a crucial role in relation to the Commission (Emerson and Nabatchi 2015). Considering the stalemate situation, highly contentious environment, and uncertainty in the debate about the coal-phase out over the years (Hermwille and Kiyar 2022; Leipprand and Flachsland 2018), the Commission presented the opportunity to get negotiating power and influence over the future of coal in Germany, as well as the distribution of funds for structural change. Furthermore, the Commission provided a starting point to collaborate across boundaries (Gürtler, Löw Beer, and Herberg 2021; Hermwille and Kiyar 2022).

The selection of members and the initial formation of the Commission also played a role in stakeholders deciding to join the Commission (Emerson and Nabatchi 2015; Gürtler, Löw Beer, and Herberg 2021). The Commission comprised four chairs and 24 stakeholder representatives with voting rights (hereinafter referred to as (Commission) members). In the run-up to the Commission, established actors were asked for advice, as well as lobbied for the inclusion of certain stakeholder groups (Grothus and Setton 2020). In the end, the Commission represented the major interest groups involved in discourse on coal in Germany at that time (Leipprand and Flachsland 2018; Markard, Rinscheid, and Widdel 2021).[119] Figure 14 shows the different general stakeholder groups represented by the Commission members. However, interests within those stakeholder groups were anything but homogeneous. For example, out of the seven regional representatives, two were against continued mining, representing communities at risk of destruction, while four were in favor of continued mining, for example, due to the impact on jobs. Considering the members' general positions regarding an early coal phase-out, around one third each of the 28 members were considered as being inclined towards an early coal phase-out, against it, or undecided, based on their institutional affiliations (Bang, Rosendahl, and Böhringer 2022; Löw Beer et al. 2021; Agora Energiewende and Aurora Energy Research 2019). All 28 members were allowed to bring along with them personal assistants without voting rights, who were referred to as 'sherpas'. In addition, three members of the German parliament (from all governing parties), eight representatives from related ministries and six members from federal states were appointed as participants without voting right – resulting in plenary sessions being held with around 100 participants. An administrative office was formed to support the Commission's work.

5.4 Coal Commission CGR: Developing joint recommendations for the German coal phase-out

In this section, we present our findings for the collaborative governance regime of the German Coal Commission. Based on the information collected in the interviews and documents, we assess how the

[119] Some people, however, criticized that no young persons and limited female representation was present in the commission (Gürtler, Löw Beer, and Herberg 2021).

Commission's members managed to find and agree on joint recommendations for a coal phase-out in Germany. In the Appendix we present the results for the full list of elements of the CGR.

The Commission convened for the first time on June 26, 2018. Nine further plenary meetings and visits to the three lignite regions of Germany were held over the next few months, culminating in a final report agreed upon by 27 (out of 28) members on January 25, 2019.[120] During its process, 67 additional external experts were invited to provide input so as to pave the way for a sufficiently fact-based decision-making process. Figure 14 shows the Commission's central recommendations, which include a phase-out pathway for German coal-fired power generation, measures to support structural change in the affected regions, and financial support and compensation.

[120] One person representing the Lusatian coal region voted against the outcome as her demands to guarantee the safeguarding of villages in Lusatia from potential destruction was not included in the final report.

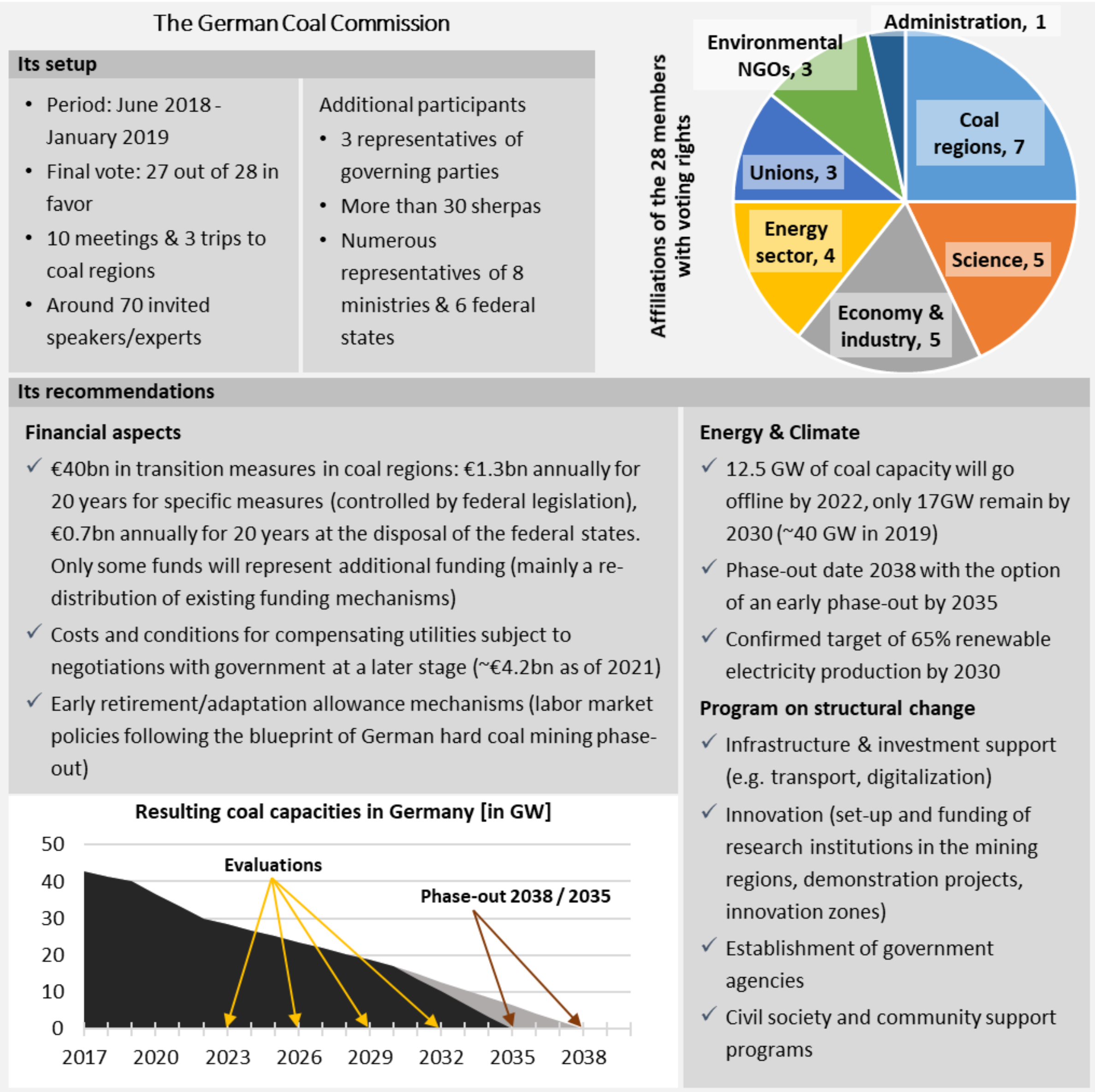

Figure 14: The German Coal Commission: set-up and results.

Source: Authors' depiction based on BMWi (2019d).

The challenge of the Coal Commission was to find compromises among the in part each other opposing objectives of the high number of involved stakeholders. Furthermore, many of the Commission's members and participants had been involved personally in the long-lasting conflict over the future of coal production and power generation in Germany, and animosities among different members existed at the start [int_5; int_11]. However, as detailed in Section 5.3 above, the mandate offered a strong incentive for stakeholders to engage in the process of the Commission and thereby potentially be able to influence German energy and structural change policies.

The expert hearings during the first meetings in the Coal Commission, the site visits, and one joint dinner offered the opportunity to get to know the other participants without having to engage in (public) fierce discussions and bargaining [int_1; int_5; int_6; int_11; int_13]. Furthermore, these exchanges, as well as the later work in small and confidential rounds, contributed to improve the mutual understanding of positions and objectives, and to build up trust between members [int_1; int_5; int_8; int_10; int_13;

int_16]. Confidence in the process and its effectiveness to find common solutions and recommendations was high among most members [int_1; int_8; int_10; int_16]. Over time, the majority of members became seriously engaged and were motivated to contribute to a successful outcome of the Commission [int_1; int_8; int_10; int_15]. Several interviewees pointed out that this built up mutual trust and understanding among members across divides of interest groups, and their shared commitment to the process were key enabling factors for constructive and enduring negotiations [int_5; int_11; int_16].

"[…] it was also a very important point in this Commission's work that Commission members from different camps trusted each other, trusted each other's professionalism, trusted each other's values, trusted each other to get through things." Interview_11.

Several interviewees mentioned that arranging more meetings of an informal nature, such as the one joint dinner, and earlier during the Commission's working period, would have been means of increasing trust and understanding among members even further [int_1; int_3; int_5; int_11]. In contrast, leaks of information from plenary assembly meetings to the press challenged the trust in others and the process itself [int_2; int_5; int_7; int_8; int_17], yet, other experienced negotiators were not surprised by leaks in such a political process [int_6; int_9].

The leaks, and the large size of the plenary assembly meetings, often with 100 or more participants, did not allow for a constructive working atmosphere in these meetings [int_10]. Members therefore rarely departed from their initial positions and little progress was made in these meetings, and the large size made it impracticable for drafting texts [int_5; int_12; int_14; int_16].

"[…] it became clear that a lot of time could pass in such a large group, but in the end, there would be no coal compromise. And then there were considerations to convene a group of people who had been in the Coal Commission, who more or less represented all groups and were accepted by all. The group was then supposed to try to discuss and negotiate all the central issues in some form in as protected a space as possible." Interview_9.

Topical split: energy vs. structural change

The commission in one of their first meetings decided to split the group in two working groups, one for "Energy Industry and Climate Targets", and one for "Economic Development and Jobs in the Regions" (BMWi 2019d, 111) to separate and ease the discussions and deliberations [int_8]. However, commission members did not want to be absent in either of the groups as the topics were closely linked and interest groups needed cohesion funds as well as phase-out dates as bargaining power. Besides agreeing on such funds, the environmental interest group had little to bargain within the discussions, except the threat of leaving the Commission [int_3; int_8]. Thus, after having met in these subgroups only once, it was decided to convene instead in the plenary assembly only [int_7].

The writing of the draft for a first report of the Commission in October 2018 was delegated to the administrative office. However, several members perceived this draft as politically influenced[121] and

[121] The administrative office of the Coal Commission, tasked with providing administrative assistance in the form of organizing expert hearings and site visits, or drafting texts, was criticized for not working transparently, as well as for reaching politically influenced decisions [int_5; int_8; int_10; int_12]. This criticism was nourished by the staffing

requested changes in the organizational and working structures of the Commission [int_5; int_11; int_14]. As a result, one of the chairs set up the first so-called *Friends of Chair* (FoC) group and selected six Commission members for it [int_11].

The Friends of Chair groups

In this first FoC group on "energy and climate", two out of six members represented environmental interests, while the others represented the energy sector, industry, and unions.[122] Members representing locally affected people were not part of this FoC [int_5; int_6; int_9]. The second FoC group on "structural development and employment" was only implemented in November, after several federal state prime ministers had intervened and demanded greater support for affected coal regions. This second FoC group mainly included members that represented local and regional economic interests, as well as employees' and employers' interests. Several interviewees stressed that the adequate choice of the FoC members was an important factor for the successful work of the FoC groups [int_5; int_9; int_11; int_13]. In particular, the FoC members needed to represent sufficiently all interest groups, be accepted by their constituency to negotiate in their name, and be willing to engage in finding compromises.

These FoC groups, although not provided with an official mandate by the Commission's plenary assembly, became central institutions of the further deliberation process on the way to the joint recommendations. In these groups, the critical details were discussed and texts for the interim and final reports prepared [int_5; int_6; int_8; int_9]. Their intimate and high-level character contributed to foster trust and shared commitment among the involved members, and a goal-oriented working atmosphere [int_5; int_9; int_11; int_13]. The confidential nature of the FoC groups allowed their members to depart from their public demands, or temporarily surpass their constituency's "red lines" (which would not have been possible in public or in the plenary), to explore possible compromises [int_5; int_9]. From their initiation on until mid of December, the FoC groups convened very frequently, often multiple times per week [int_5]. In this process, the sherpas of the FoC members played an important role, meeting in FoC sherpa rounds, and preparing text drafts that then were further discussed and refined by the FoC members to be then introduced in the plenary assembly [int_5; int_10; int_11]. The plenary assembly remained the institution, where decisions had to be passed by a two-thirds majority to be included in the Commission's recommendations.[123]

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of the administrative office, which was thought to be politically motivated. For example, some staff had been posted from administrations of affected federal states [int_5; int_8].

[122] Members of the FoC energy & climate: Stefan Kapferer (BDEW), Stefan Körzell (DGB), Holger Lösch (BDI, Dieter Kempf's sherpas), Felix Matthes (Öko-Institut), Kai Niebert (DNR), and Katharina Reiche (VKU). Members of the FoC structural development & employment: Christine Herntier (Mayor of Spremberg), Steffen Kampeter (BDA), Michael Kreuzberg (Head of the District Authority of Rhein-Erft-Kreis), Matthias Platzeck (Commission Chair), Reiner Priggen (Landesverband Erneuerbare Energien NRW), Gunda Röstel (Stadtentwässerung Dresden), Christiane Schönefeld (Federal Employment Agency), Stanislaw Tillich (Commission Chair), and Michael Vassiliadis (IGBCE). Source Löw Beer et al. (2021).

[123] While the mandate for the Coal Commission included the objectives and the list of appointed chairs and members, it did not specify the working procedures of the Commission. Thus, one of the first tasks of the Commission was to agree on and pass procedural rules for its work, which happened during the first plenary assembly meeting of the Commission [int_3; int_10]. It was determined that decisions would have to be passed by the members with a two-thirds majority in the plenary assembly, which should guarantee that no decision could be passed without the consent of one of the major interest groups [int_3].

The night of the final negotiations

The general parts of the final report were prepared by the FoC groups and the administrative office, and decided upon in the plenary assembly. However, key issues, like the concrete phase-out pathway and end date, and the size of the structural change fond, remained open questions and were not talked about in the plenary until the last day of the Commission [int_5; int_7; int_10]. After convening in the plenary assembly during the last day without resolving these issues, members of the FoC and the chairpersons met separately to negotiate compromises for these points [int_5; int_11].

First, a decision on the part on structural change was made, before starting the final negotiations on the coal phase-out pathway and date. Thus, compromises concerning the latter issues had to be reached within this same field, excluding compromises including structural change questions [int_3]. Furthermore, members of the environmental group generally supported demands for a just transition for workers and structural change in the affected regions, which members of the unions did not rejoin by an equivalent support vice versa. This eventually weakened the negotiating position of the environmental side towards the unions regarding an early phase-out [int_1].

These negotiations were led rigorously among the participants, including the utilization of the short-term absence of individual members to change previously reached formulation decisions with these members [int_11]. The members participating in these discussions then met during several pauses with the other members of their interest groups to consider possible compromises and red lines, and continue the negotiations based on these interest group positions [int_5; int_11]. Despite continuously large conflicts of interest and the tough style of the negotiations, members finally reached compromises for all remaining issues [int_11]. This was also driven by the fear of an overall failure of the Commission, if no solution would have been found during that night; the continuation of talks on the next day was no option due to the risk of leaks and resulting external pressure in case of any interruption of the negotiation talks [int_6; int_11].

The Commission's chairs

The role of the chairpersons was described as very ambiguously. Many of the interviewees perceived the chairs as advocates for certain interests,[124] and counterpart for the associated interest groups only, rather than as neutral moderators [int_3; int_9, int_12]. Several interviewees also criticized missing concepts and moderation by the chairs to facilitate more inclusive exchange and communication within the Commission, and effective problem-solving approaches [int_5; int_11; int_13]. In the beginning, it remained unclear how the Commission would arrive at joint decisions or who would write the Commission's reports [int_3; int_7].

"[…] I don't think anyone [of the chairpersons] really had a concept of how a Commission has to go through different phases and then also come to results, which to some extent sees the different interests and then creates a balance of interests instead of the smallest common compromise." Interview_3.

[124] Two chairs were associated with the structural and economic interests of coal regions, one was perceived as also representing Federal Government interests and one was associated with environmental interests.

On the other hand, several interviewees mentioned that the leadership by the chairs, and particularly by one of the chairs, who was perceived by many as the unofficial leader of the Commission (due to being most partisan and well connected to the government), was very important for the successful deliberations and decision-making in difficult situations [int_6; int_7; int_13; int_15; int_16]. It was also this chair who had chosen the members of the first FoC group, which was perceived as an important decision for the successful deliberations in this group [int_5; int_9; int_11; int_13].

Role of federal state representatives and national government

The federal states had representatives in the Commission in the form of two former federal states prime ministers, serving as chairs. In addition, each affected federal state could appoint an additional representative, sometimes being the active federal (prime) ministers having no voting rights but still very active participation during all sessions [int_3; int_5; int_11].

"[…] the prime ministers […] not unskillfully maneuvered in such a way that the federal states had the right to intervene and speak in the Commission at any time. They made extensive use of this […] so that the federal states were very, very strongly represented in the Commission with their statements." Interview_16.

It was considered important to address the interests of the federal states, as it was clear to the Commission members that they could potentially block the implementation of measures at a later stage [int_5; int_8; int_11]. The federal state governments involved had been strong supporters of continued coal mining in the past (Hermwille and Kiyar 2022). Furthermore, the (former) prime ministers of Eastern federal states continuously expressed the fear of an early coal phase-out driving voters into the arms of the party of the extreme right, the *Alternative für Deutschland* (AfD), at the then upcoming federal elections [int_1; int_7]. In November 2018, the Commission was about to agree on the first part of the final report on measures for structural change. However, the prime ministers considered the foreseen funds for affected regions as too low. Subsequently, Chancellor Merkel ordered the Commission to resume its work and revise its recommendations, effectively delaying the Commission and potentially increasing total funds for the coal regions [int_5; int_6; int_14].

The possibility to make relatively unrestricted recommendations for the size of the fund for structural change, the establishment of which was provided for in the mandate, comprising primarily federal resources (BMWi 2019d), provided an important leverage for compromises. Federal state governments were willing to give up their opposition to the coal phase-out to some extent in turn for financial compensation [int_5; int_6; int_12; int_15].

"[...] because whether they get another billion or not for structural measures - that's decisive for a prime minister when he says I'm also getting the railway line. For the environmental side, which is fighting for the climate, it doesn't matter." Interview_16.

The Federal Government was furthermore indirectly involved in the Commission's work through its close contact to one of the chairs [int_9; int_14]. The ministries' representatives were not publicly active within the plenary sessions, but in the background, had continuous close consultations to check whether the discussed proposals could actually be implemented [int_11; int_16].

Members' participation possibilities and influence

Most interviewees stressed the different roles and participation possibilities of the individual Commission members. Depending on their negotiation experience, connectedness, expertise, and available resources (e.g., time, staff), members had higher or lower chances to influence the Commission's work [int_7; int_9; int_11] (also see Table 9 in the Appendix). As described above, key deliberation processes took place outside of the plenary assembly, for example, in the FoC groups or bilateral talks in between sessions. Even though several interviewees stated that, the composition of FoC groups represented all interest groups [int_5; int_6; int_9; int_13], access to these groups remained exclusive [int_11]. This limited the possibility for many members to participate in deliberating the core contents, because they were constrained to introduce their opinion into these groups via other members of their interest groups [int_3; int_4; int_13; int_15]. For the coordination and consultation within interest groups, these met separately from the other Commission meetings throughout the process of the Commission [int_5; int_11]. Many decisions, like who would belong to the FoC groups, were not discussed nor decided by the plenary assembly, but by the chairs after consulting with individual members [int_3; int_5; int_11; int_12]. Members without experience in such processes found it hard to know how to introduce and enforce their demands in the right way, at the right place and the right time [int_4; int_12]. For example, while all members were able to make demands and suggest topics for debate in the plenary assembly, topics usually had to be supported by other influential members or FoC groups to be considered for debate within the FoC groups where the first drafts of documents were written [int_16].

5.5 Discussion

In the above analysis, we show how the German Coal Commission reached an agreement on the future of coal supported by all major interest groups (Hermwille and Kiyar 2022). Stakeholder commissions as such provide opportunities to resolve stalemate situations and to trigger off a ratcheting up of climate ambitions in the aftermath. In Germany, the coal phase-out was advanced from 2038 to 2030 by the next government (Bang, Rosendahl, and Böhringer 2022). Yet, the Commission was also criticized for delivering a late and expensive coal phase-out within their recommendations. In the following, we discuss our findings on how the Commission achieved to breach the stalemate situation and how its final recommendations were formed.

The Commission created and fostered a collaborative environment, enabling the cooperative work on finding joint solutions. It provided a space for individuals representing the various interest groups to get to know each other on a personal level and engage in a direct exchange. This contributed to increase the level of mutual understanding and trust, and the willingness to find an agreement. This can be considered a major achievement of the Commission compared to the previous situation, in which pro- and contra-coal interest groups formed "enemy camps" (Grothus and Setton 2020, 283). Despite some drawbacks (e.g., limited opportunities for informal exchange among participants; insufficient confidentiality of Commission meetings), the Commission's members developed a shared commitment to engage intensively to achieve the Commission's objectives, a precondition for successful collaborative policy formulation processes (Ansell and Gash 2007; Emerson, Nabatchi, and Balogh 2012).

However, the willingness of the different interest groups to participate and engage in such a collaborative approach, working on compromise-based policy recommendations, depends on the lack of alternatives to enforce a unilateral policy formulation (Emerson and Nabatchi 2015; Sabatier and Weible 2007). The context of the German Coal Commission was characterized by the highly contested and uncertain future of coal, the lack of sufficient power for one interest group or coalition to enforce their interests (Hermwille and Kiyar 2022), and political parties with more to lose than to gain from taking the responsibility for a decision (Löw Beer et al. 2021). In this situation, leaving the decision to a stakeholder commission offered policymakers the possibility to dilute responsibility and gain legitimacy for a derived policy (Gürtler, Löw Beer, and Herberg 2021), and interest groups the possibility to actively shape a possible policy formulation. On the other hand, the participants knew that it would be very difficult to enforce their interests outside of the Commission, and leaving the Commission would have born the risk of leaving the decision up to others.

Yet, aligning the objective of an early coal phase-out with (local) economic and political interests remained challenging. In the Coal Commission, this dilemma was eased by public funds at hand of the Commission to distribute among affected stakeholders – substantially burdening the taxpayers, without having them explicitly represented. This was possible to do so in Germany, given its economic capacities, and may not be possible in countries with less economic capacities or in times of crisis. In historic comparison, costs implied by these recommendations amount to only about one-fifth to one-third of the sum of subsidies paid to hard coal production in Germany between 1950 and 2008 (Hermwille and Kiyar 2022). Nevertheless, high costs and payments to individual stakeholders, if perceived as not serving the common good, bear the risk of reducing an agreement's legitimacy (Gürtler, Löw Beer, and Herberg 2021). The commission's composition was perceived as relatively balanced and comprehensive, including representatives from locally affected people, industry, unions, environmental associations, science, and regional and national politics. Thus representing the major coalitions involved in discourses on coal in Germany during that time (Markard, Rinscheid, and Widdel 2021). Regarding gender aspects the Commission was less balanced, with only ten female members out of 28. Although jobs in the affected regions are likely to be created in the service sector, in which women make up the majority of employees (Walk et al. 2021), discussions focused heavily on male dominated industrial jobs. However, to achieve just transitions in coal regions for all, it is key to actively consider gender aspects throughout the entire process (Braunger and Walk 2022).

Gürtler et al. (2021) find that the German Coal Commission partly derived its legitimacy from its bottom-up rhetoric of including regional stakeholders' interests, yet ultimately led to recommendations for top-down policies. One reason for the limited bottom-up character of the recommendations might have been, apart from the comprehensive mandate (Gürtler, Löw Beer, and Herberg 2021), the difficulties of stakeholders representing local interests to participate effectively in the Commission process, due to limited negotiation experience and other resources. Few influential members of the Commission drafted and decided largely upon key contents of the final recommendations, a regular issue of such participatory processes (Brisbois and Loë 2016). A leadership more sensitive to such power imbalances as well as additional resources to level the playing field might be able to remove some of these barriers (Newig et al. 2018b). In addition, younger generations and perspectives from countries most affected by the climate crisis were barely represented.

Overall, the Commission facilitated the members to decide on joint recommendations and with this overcoming the stalemate in the contentious environment. While the collaborative setting contributed to reconciling previously heated and emotional debates, it was also the very specific contextual situation at that moment in time in Germany that all veto players considered participating in the Commission and passing a joint agreement as best option to pursue their political interests.[125] Furthermore, the relatively costly approach with large public funds for structural change and other measures raises the question to what extent the German Coal Commission case could be an example for other phase-out decisions (Hermwille and Kiyar 2022). Considering economic possibilities and functioning of government, similar processes to promote a just and timely coal phase-out might also be an option for some other major coal producing and consuming countries like Australia or the USA (Jewell et al. 2019).

Limits to our study include, that it cannot be determined for sure whether a counterfactual policy formulation process, for example, a citizen forum, or simply a decision by the Federal Government would also have achieved a coal phase-out agreed upon by the diverse interest groups. Furthermore, our study is based on a single case in a wealthy country. Another advantage for the German coal commission was the existence of numerous studies that had investigated potential techno- and socio-economic effects of different coal phase-out scenarios in Germany. Since energy transitions in general are very context-specific processes, it is rather difficult to generalize our results. A comparative study, possibly including other forms of collaborative institutions such as citizen assemblies, could nevertheless help to improve our understanding of the possibilities of collaborative governance approaches to manage phase-out processes in line with ambitious climate targets.

5.6 Conclusions

The recommendations of the German "Commission on Growth, Structural Change and Employment" on a coal phase-out pathway and structural change measures were a major step to ending the use of coal in one of the world's major coal consuming countries, easing the following decision by Europe to target climate neutrality by 2050. Prior to the Commission, the situation was "highly contentious" with counteracting objectives and heated debates between different interest groups leading to a stalemate situation in the debate about the necessary coal phase-out.

This paper explores the role of the Coal Commission to reach joint recommendations in the debate on the coal phase-out in Germany and how they were formed. We find that the Commission helped to find joint recommendations and overcome long standing stalemate situation by providing a safe space to build up trust and understanding which was important considering the highly contentious situation. The broadly defined mandate and the provision of public funds by the Federal Government largely defined the possible solution space for the Commission. It provided the mandate and significantly influenced the willingness of incumbent actors to participate and agree on a phase-out by offering high compensation

[125] Not considered here due to the scope of the study, but relevant for further considerations are the later differences in the two laws that were passed to implement the coal phase-out and structural change processes compared to the Commission's recommendations. Therefore, key members of the Coal Commission publicly withdrew their support. Deutscher Naturschutzring. 2019. "Mitglieder der Kohlekommission zur Aufkuendigung des Kohle-kompromisses?" Accessed March 31, 2022. https://www.dnr.de/presse/pressemitteilungen/mitglieder-der-kohlekommission-zur-aufkuendigung-des-kohle-kompromisses?L=928.

payments to affected regions and companies. The political and economic pressure and absence of other alternatives contributed to actors' willingness to engage in the Commission and find joint recommendations. Having shifted discussions in Germany from if to how to do a coal phase-out, enabled the next government to move the agreed-on phase-out date from 2038 to 2030.

Critical aspects concerning the work within the Commission are the fact that existing power imbalances influenced the way members could participate resulting in a domination of the decision-making process by certain members. Never-the-less, the Commission managed to overcome a decade-long stalemate that several other attempts by the government had failed to resolve. Its findings, are highly context specific, but provides valuable insights for other coal phase-out debated and participatory governance approaches. Further research can examine similar processes in other countries to draw overarching conclusions.

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7 Appendix

7.1 Overcoming political stalemates: The German stakeholder commission on phasing out coal

7.1.1 Collaborative Governance elements in the Coal Commission

Principled Engagement		Description	Importance for process
Discovery	Expert hearings and site visits in coal mining regions	67 external experts were heard in the first Commission meetings; Field trips to three lignite regions of Germany	Opportunity for participants to highlight their positions (by inviting specific experts) and to get to know other participants and their positions outside of bargaining situation [int_1; int_5; int_6; int_13]; Varying perception of added informational value depending on participants' previous knowledge levels [int_5; int_10; int_13]
Definition	Mandate	Mandate provided definition of tasks and goals	Discussion of interpretation of mandate in Commission meetings, but as each interest group persisted on the most favorable interpretation in their sense the initial mandate remained the point of reference [int_1; int_5; int_13; int_16]
	Content related definitions		No joint synthesis or definitions of common knowledge made [int_3; int_13];
Deliberation	Plenary assembly	Often more than 100 participants; public character [int_10]	Members rarely departed from their initial positions, leaving little room for constructive compromise [int_12]; E.g., ultimate phase-out date was not seriously discussed in the plenary session until the last night [int_11]
	Deliberation of core contents	Took place mostly outside of the Coal Commission's plenary assembly, e.g., in FoC groups	Members without access to the other formats – such as FoC groups – where controversial topics were discussed, were largely excluded from the direct process of deliberating the core content [int_13; int_15; int_4]; Confidential nature of the FoC groups allowed their members to depart from their public demands, or temporarily surpass their constituency's "red lines" (which would not have been possible in public), to explore possible compromises [int_9; int_5].
	Agenda setting		All members were able to make demands and suggest topics for debate in the plenary session, such topics only had little chance of being discussed in further depth unless they were supported by other influential members or FoC groups [int_16]
Determination	Procedural rules	No preset procedural rules but had to be decided upon by the members in first meetings	Procedural rules passed at the start of the Commission; Some procedural arrangements changed in the course of the process, such as the creation of FoC groups. Individual or group influence on these arrangements varied [int_3; int_10; int_11; int_12]
	Official decision process	Final decisions required voting in plenary assembly	Drafts for key elements, such as the procedural rules, meeting agendas, and the interim and final reports, were prepared by the administrative office, the chairs, and the FoC groups [int_10; int_11; int_14; int_18]
	Unofficial decision processes	Many decisions based on informal talks and meetings;	Decisions on additional arrangements (e.g., FoC);

Principled Engagement		**Description**	**Importance for process**
		decisions taken by the chairs [int_3; int_5; int_11; int_12]	Selection of possibilities to be available for final vote
Shared Motivation		Description	Importance for process
Trust	Historic relations of participants	Personal relationships from interactions prior to Commission's work	Relatively strong distrust between some individual members [int_2; int_5; int_8]
	Site visits and joint dinner	Field trips to coal regions with all Commission members; one joint dinner	Informal atmosphere allowed sharing positions more freely, and building personal relationships [int_5; int_11]
	Information leaks	Information from Commission meetings and discussions was forwarded unofficially to the press	Leaks were perceived as a standard procedure by those with more experience in political negotiation processes, while members with less experience perceived them as a breach of trust and disappointment in the group. In general, the high media attention made work in the Commission difficult [int_2; int_5; int_8; int_17].
	Personal ties	Large size of commission (number of members); limited number of informal meetings	It was not possible to build a personal bond with all members due to the size of the Commission and the lack of informal meetings [int_2; int_5; int_8].
Mutual Understanding	Site visits		Site visits and exchange fostered understanding of actors' objectives and constraints [int_1; int_10]
	Joint work in Commission		The atmosphere improved over time and it was possible to establish respectful interaction "at a distance" throughout the Commission [int_5; int_13]. Some members were able to find "a common language" across interest group borders, while others struggled, depending on their personality and their experience with negotiation processes [int_11]
	Attendance of individual members during assembly meetings	a few members were repeatedly absent	difficult to establish personal relationships or trustful collaboration with them [int_2; int_5]
Internal Legitimacy			High confidence in the process and its effectiveness among most members [int_1; int_8; int_10; int_16];
Commitment	Joint work in Commission		Rapprochement among Commission members, and a common desire to reach a compromise [int_15; int_16]
Capacity for Joint Action		Description	Importance for process
Procedural and Institutional Arrangements	Plenary assembly	Members (voting right) + sherpas + non-member participants ; Right to speak for federal state representatives	Federal state representatives very actively involved as speakers [int_16]
	Sherpas	Members' assistants (no voting right)	Important role, engaged in exchange, discussion, and coordination outside the limited meeting times [int_10; int_11]
	Friends of Chair (FoC) groups	1) "energy and climate" (from August on, six members) 2) "structural development and employment" (from November on; seven members)	Critical details were mainly discussed in these small circles involving only a few members [int_5; int_6; int_9]
	Interest groups	members with similar interests formed interest groups to discuss possible	Deliberation space within interest groups and possibility for members without seat in FoC to

Principled Engagement		Description	Importance for process
		negotiation strategies, red lines for compromises, and demands	introduce and discuss negotiation points for FoC meetings [int_12; int_13; int_16
Leadership	Chairs (four)	Selected and appointed by government; Task to lead Commission's work and meetings	Very different roles taken by the four chairs; Large discrepancies in political experience and personal networks, resulting in different levels of power and influence; Perceived as advocats for certain interest groups instead of neutral moderators [int_3; int_9; int_12]; Important role in moderation of negotiations [int_15]; No concept/strategy to balance stakeholders' interests and achieve compromise [int_3]
	Administrative office	Organizational work of Commission (e.g., site visits, plenary meetings), provision of text drafts, meeting agendas	Non-transparent working procedures and politically influenced [int_5; int_8; int_10; int_12]; Staff from ministries and administrations of affected federal states not perceived as neutral [int_5; int_8]
Knowledge	Expert hearings		No joint synthesis or definitions of common knowledge made [int_3; int_13];
	Expert hearings		Debates were generally based on scientifically sound and by experts supported arguments [int_17]
Resources	See Table 10		

Table 9: Elements of collaboration dynamics in the Coal Commission.

7.1.1.1 Capacity for joint action

The element of ***procedural and institutional arrangements*** encompasses all formal and informal structures of the Coal Commission to enable discussions and to reach a compromise. The institutions included a plenary assembly involving all members, the inclusion of at least one assistant per member, referred to as sherpas, and a division between Coal Commission members with voting rights and non-member participants without voting rights who were able to participate in the general exchange and discussion. The sherpas played an important role because they also engaged in exchange, discussion, and coordination outside the limited meeting times [int_10; int_11].

One important arrangement that emerged during the work of the Coal Commission were the so-called *Friends of Chair* (FoC) groups. Critical details were mainly discussed in these small circles involving only a few members [int_5; int_6; int_9]. The ability to work and meet in smaller groups was an important aspect on the path to a compromise, given that they offered the opportunity for more concrete and confidential discussions. Furthermore, since the size of the plenary assembly made it an inappropriate instrument for writing texts for the interim and final reports, the FoC groups provided the opportunity to draft such texts. Even though several interviewees stated that the composition of FoC groups represented all interest groups [int_5; int_6; int_9; int_13], the meetings remained exclusive and non-transparent [int_3; int_11; int_15]. The first FoC group on “energy and climate” was set up in August after several members approached the chairs requesting changes in the Commission’s working structures because little progress had been made in the general sessions [int_5; int_14]. Two out of six of the first FoC’s members represented environmental interests, while the others represented the energy sector, industry, and unions.[126] The second FoC group on “structural development and employment” was only implemented in November, after several federal state prime ministers had intervened and demanded greater support for affected coal regions. This group mainly included members that represented local and regional economic interests, as well as employees’ and employers’ interests. Furthermore, members from environmental associations, for instance, were generally also in support of the demands for just transition and structural change processes [int_1], ultimately leaving them with little to offer the unions in return for their support for an earlier phase-out. Furthermore, this split into these two FoC groups also separated the deliberations on energy and climate issues on the one hand, and structural development and employment issues on the other.

In addition to establishing FoC groups, members with similar interests formed interest groups to discuss possible negotiation strategies, red lines for compromises, and demands. Another arrangement concerned the participatory possibilities of federal state representatives. The members decided that federal state representatives should have the right to speak during the Commission’s meetings [int_10], which they proceeded to make extensive use of [int_16].

The chairs had different roles in the ***leadership*** of the Coal Commission, mainly due to their diverse political experience and personal networks, resulting in different levels of power and influence. Two chairs, former prime ministers of federal states with coal mining regions, were associated with the structural and economic interests of coal regions. Another chair, a former federal minister, was perceived as also representing Federal Government interests, due to his being in constant exchange and contact with the government. The fourth, a university professor, was associated with environmental interests. The chairs were perceived by many of the interviewees as advocates for certain interests, rather than as neutral moderators [int_3; int_12, int_9]. One interviewee noted that the chairs often only saw themselves as responsible for a certain group [int_12], which reinforced the power imbalance and unequal treatment of members. Interviewees generally described interaction with the four very different chairs as being challenging [int_3; int_6; int_11; int_9]. However, one interviewee pointed out that the different positions were brought together by the chairs, and especially by one chair due to his political experience [int_15].

Overall, cooperation among chairs and the administrative office, as well as with governmental institutions, was considered rather weak [int_5; int_8]. In particular, it was criticized that there was no concept of how the Coal Commission was to reach a compromise that actually balanced the stakeholders’ interests, rather than simply achieving the lowest common denominator [int_3]. The administrative office, tasked with providing administrative assistance to the Coal Commission in the form of organizing expert hearings and site visits, or drafting texts, was also criticized for not working transparently, as well as for reaching politically influenced decisions [int_5; int_8; int_10; int_12]. This

[126] Members of the FoC energy & climate: Stefan Kapferer (BDEW), Stefan Körzell (DGB), Holger Lösch (BDI, Dieter Kempf’s sherpas), Felix Matthes (Öko-Institut), Kai Niebert (DNR), and Katharina Reiche (VKU). Members of the FoC structural development & employment: Christine Herntier (Mayor of Spremberg), Steffen Kampeter (BDA), Michael Kreuzberg (Head of the District Authority of Rhein-Erft-Kreis), Matthias Platzeck (Commission Chair), Reiner Priggen (Landesverband Erneuerbare Energien NRW), Gunda Röstel (Stadtentwässerung Dresden), Christiane Schönefeld (Federal Employment Agency), Stanislaw Tillich (Commission Chair), and Michael Vassiliadis (IGBCE). Source Löw Beer et al. (2021).

criticism was nourished by the staffing of the administrative office, which was thought to be politically motivated. For example, some staff had been posted from administrations of affected federal states [int_5; int_8].

A large number of experts were invited to speak on different topics. However, several interviewees mentioned limited efforts to create a shared ***knowledge*** base [int_3; int_11; int_15]. Especially established and well-informed members had a limited interest in reducing knowledge deficits of other members or in revisiting their own positions and creating a common knowledge base [int_1; int_5; int_9]. Although specific information was requested from external experts, no joint synthesis of the presented expert input or definitions of common knowledge was prepared [int_3; int_13]. However, debates were generally based on scientifically sound and by experts supported arguments [int_17].

Collaborative ***resources*** may take different forms, such as time, funding, technical and logistical support, power, and expertise (Emerson, Nabatchi, and Balogh 2012). Resource disparities and mismanagement can affect the outcome and the “perceived and real fairness, legitimacy, and efficacy of CGRs” (Emerson, Nabatchi, and Balogh 2012, 16). Table 10 describes the identified differences in resource endowment, grouped into five resource types. Overall, the differences in expertise, capacity, and financial resources led to the actors’ different starting conditions and the differences in the opportunities to engage in the process [int_11; int_9; int_7]. It was mentioned that although it was difficult to fully erase the initial resource disparities, it was possible to compensate for some of them [int_11].

Type of resource	Resource disparity	Perception and influence on the process
Time / financial / organizational	Voluntary members of organizations vs. boards of large industry associations	• No level playing field regarding organizational support [int_9]. • Results in power disparities and fewer time resources for the Coal Commission [int_12].
	Majority of formal and informal meetings held in Berlin	• Difficult for members who do not live or work in Berlin [int_7; int_11].
	Time	• Need to prioritize which (informal) meetings to attend [int_7].
Human resources	Differences in staffing	• Differences in staff support and organization of support [int_15; int_12; int_13; int_7] → power imbalance [int_12; int_2].
Network	Different network with chairs	• Differences lead to different treatment of members [int_12].
	Links between some members (before the Coal Commission)	• Agreements in informal meetings: difficult for members outside Berlin to comprehend processes and decisions [int_11]. • People with a stronger existing network who knew each other had more opportunities to influence the outcome. • However, few new connections between interest groups were formed [int_11].
Negotiating and political experience	Understanding the way things work	• More work for people without experience (reading “all” the papers) [int_4]. • At the beginning especially, it remained unclear, particularly for inexperienced members, how decisions were to be reached, and who would decide on the agenda or write the reports [int_12; int_5; int_11].
	Negotiation experience	• Correlation of level of experience and influence on outcomes [int_8; int_3; int_2]. Several personalities are said to have had a larger influence on the Coal Commission, especially due to their goal orientation, capacity in building compromises, and in-depth knowledge [int_5; int_9; int_10; int_13; int_16]. • Negotiating and strategic experience helped to steer decisions.
Expertise (knowledge)	Access and capacity to gain sector-specific knowledge	• No level playing field due to disparities in knowledge and access to information [int_9].

Table 10: Identified differences in resource endowment.

7.1.1.2 Principled engagement

For successful principled engagement, it is important that participants ***discover*** the interests and positions of others, enabling them to acquire expert knowledge in the broad field of topics addressed. During the first few months of the Coal Commission, information and insights were provided by 67 expert hearings, as well as field trips to coal mining regions. Interestingly, participants assessed this input very differently. Some stated that they acquired a lot of new information thanks to this input [int_10], while others gained little from these processes [int_13; int_5]. However, some of the particularly well established and informed actors emphasized that these processes gave them the opportunity to highlight their own positions, and to get to know the other participants without having to engage in fierce discussions and bargaining [int_6; int_13; int_5; int_1].

The ***deliberation*** on the main decisions largely took place outside of the Coal Commission's plenary assembly. In the plenary discussions, members rarely departed from their initial positions, leaving little room for constructive compromise [int_12]. This was due at least in part to the ultimately public nature of the plenary meetings, caused by constant leaks to the public, as well as the size of the meetings, often with 100 or more participants [int_10]. As an example, the debate on the ultimate phase-out date was not seriously discussed in the plenary session until the last night [int_11]. Members without access to the other formats – such as FoC groups – where controversial topics were discussed, were largely excluded from the direct process of deliberating the core content [int_13; int_15; int_4]. Although all members were able to make demands and suggest topics for debate in the plenary session, such topics only had little chance of being discussed in further depth unless they were supported by other influential members or FoC groups [int_16]. The confidential nature of the FoC groups allowed their members to depart from their public demands, or temporarily surpass their constituency's "red lines" (which would not have been possible in public), to explore possible compromises [int_9; int_5].

The element of ***definition*** was rather implicit in many instances and is intertwined with ***determination***. For example, the understanding of the tasks and expectations of the Coal Commission according to the political mandate introducing the Commission was discussed among the members [int_13; int_5; int_16], yet no side was willing to accept a more favorable interpretation for their opponents [int_1; int_5]. Similarly, the interpretation of expert information, as stated above, was subject to each participant's own judgement, since no joint synthesis of the presented expert input was prepared [int_13; int_11]. The procedural rules were discussed and passed at the start of the Coal Commission. However, some procedural arrangements changed in the course of the process, such as the creation of FoC groups or the right of federal state government representatives to speak. Individual or group influence on these arrangements varied [int_12; int_10; int_3; int_11].

As with the deliberation of core elements, determination was also linked to the work of FoCs and other small groups. However, final decisions had to be reached in the plenary assembly. Drafts for key elements, such as the procedural rules, meeting agendas, and the interim and final reports, were prepared by the administrative office, the chairs, and the FoC groups [int_18; int_10; int_11; int_14]. However, many of the underlying decisions on content, or who would belong to the FoC groups, were not discussed or decided in the plenary session, but were based on informal talks and meetings, and decisions were taken by the chairs [int_12; int_3; int_5; int_11]. Another prominent example of this non-transparency was the gathering of a small number of members on the very last night of the Commission to bargain over the remaining unresolved questions, such as the phase-out date. The members who were not party to this special meeting simply noticed at some point that all of the chairs and some of the members were no longer present in the Coal Commission meeting room [int_11]. Members without experience of such bargaining processes found it hard to know how to introduce and enforce their demands at the right place and the right time.

Decisions on the mandate and Commission members during the pre-Commission phase were not part of the Coal Commission's internal processes, but may well have largely determined its course: Some established members were also involved in the development phase of the Commission. For example, government officials asked them to comment on the selection of invited stakeholders or they themselves attempted to influence the wording of the mandate. Some were completely surprised by the call asking them to participate, while others were closely involved in discussions about the Coal Commission before it was officially launched [int_5; int_11; int_12; int_4].

7.1.1.3 Shared motivation

Trust and ***mutual understanding*** build the basis for collaboration among participants. In the Coal Commission, events that were frequently referred to in this regard were the field trips to coal regions and a joint dinner. For example, one interviewee mentioned that he became aware during these trips that trade unions are membership organizations, which helped him to understand those actors' constraints [int_1]. Others stated that they gained a better insight into the local situation in the coal regions [int_10]. Several members emphasized their appreciation of the joint dinner organized on one of the trips. This dinner was one of the rare occasions when members were able to meet in an informal atmosphere. This enabled them to share their positions more freely, and to build more personal relationships. Several interviewees mentioned that arranging more meetings of such nature would have been a means of increasing trust and understanding among members [int_5; int_11].

Generally, the atmosphere improved over time and it was possible to establish respectful interaction "at a distance" throughout the Commission [int_5; int_13]. Some members were able to find "a common language" across interest group borders, while others struggled, depending on their personality and their experience with negotiation processes [int_11]. There was rapprochement not only among individuals, but also in the whole group, and a common desire to reach a compromise [int_15; int_16], leading to a shared ***commitment***.

However, a latent sense of mistrust shaped the work of the Coal Commission because several aspects limited the trust-building process:

- Leaks: Information was constantly leaked to the press, which made trusting cooperation more difficult. However, this was perceived differently by different actors. Leaks were perceived as a standard part of the process by those with more experience in political negotiation processes, while members with less experience perceived them as a breach of trust and disappointment in the group. In general, the high media attention made work in the Commission difficult [int_2; int_5; int_8; int_17].

- Attendance: Presence at meetings is particularly important for shared motivation. Only a few members were repeatedly absent, making it difficult to establish personal relationships or trustful collaboration with them [int_2; int_5].
- Personal ties: It was not possible to build a personal bond with all members due to the size of the Commission and the lack of informal meetings. Interviewees referred to a relatively strong distrust between some individual members [int_2; int_5; int_8].
- Administrative office: Since the administrative office was perceived as being biased, some members found it difficult to work with it.

The federal state prime ministers played a special role. Several interviewees considered their behavior to be negative for the process [int_16]. The prime ministers were described as dominant in the plenary sessions, although they only had the right to speak, and not to vote. Furthermore, their major influence became apparent from their interactions with the Federal Government in general, and in particular from the decision on funds for affected regions in November 2018. These funds led to an intervention by Chancellor Merkel, effectively delaying the Coal Commission and potentially increasing total funds for the coal regions, although all Commission members had already agreed on a compromise.

Internal legitimacy refers to individual members' confidence in the process and the effectiveness of the Coal Commission. Confidence in the process and its effectiveness was high among most members [int_1; int_8; int_10; int_16], although there was some disillusionment about the possibilities to have their own positions included in the final report [int_12]. However, most members had serious intentions to find a solution, and were committed to the process, even though it was not clear at the beginning what the final outcome would be, and how the agreements would be incorporated into the political process.