Coal and natural gas lock-ins:

Analysis of drivers and barriers of phase-outs to accelerate sustainability transitions

vorgelegt von

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an der Fakultät VII – Wirtschaft und Management

der Technischen Universität Berlin

zur Erlangung des akademischen Grades

Doktorin der Wirtschaftswissenschaften

– Dr. rer. oec. –

genehmigte Dissertation

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Tag der wissenschaftlichen Aussprache: 27.05.2021

Berlin 2021

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Submitted at the School VII – Economics and Management

Technische Universität Berlin

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Day of the public defense: May 27, 2021

Berlin 2021

Abstract

The dissertation focuses on sustainable energy transitions, forming one part of climate change mitigation strategies. It combines economic, political, technical, and social aspects to analyse energy transitions of different fossil energy carriers, namely hard coal, lignite, and (liquefied) natural gas. It covers the transition processes of phase-out, lock-in, and 'phase-in'. Globally, energy transitions are still too slow to achieve emission reductions on the required scale. The acceleration of sustainability transitions is undermined not just by a lack of political and economic feasibility, but also insufficient knowledge on governance possibilities. By combining insights on different fuels, transitions phases, and geographic scopes, this dissertation aims to answer research questions regarding what lessons can be learned for upcoming transitions from past phase-outs and ongoing transition processes, which mechanisms create lock-ins into coal and natural gas, which barrier natural gas poses to sustainability transitions, and which policy measures can facilitate fossil fuel phase-outs.

Three chapters of this dissertation comprise case study evidence on (i) lessons from the historical hard coal mining phase-out in Germany; (ii) the political economy of reducing coal use in Poland; and (iii) the risk of Germany creating a further lock-in with natural gas with Liquefied Natural Gas terminal investments. Chapter five systematically maps the risks and barriers that natural gas poses for energy transitions. In summary, I find that inertia and resistance to coal and natural gas phase-outs are caused by industrial actors, unions, civil society, and policy actors. I show that strong technological and infrastructural, institutional, behavioural, and discursive lock-ins of coal and natural gas exist. For coal, based on the analysis of techno-economic and socio-political environments as well as economic, social, and geographical indicators, policy recommendations on how to manage the decline of coal are derived. For natural gas, I add to the scientific debate on the role it might play in sustainability transitions and identify explicit mechanisms of how lock-ins and sustained policy support for this fossil fuel are created.

The main four contributions to the academic literature are (1) a new methodological approach that combines actor and material analyses to study energy transition; (2) an improved understanding of the powerful inertia dominant regimes around coal and natural gas can impose on transitions; (3) a systematic overview of the scant evidence on risks associated with natural gas' role in sustainability transitions; and (4) the identification of feasible transition policies and pathways for upcoming fossil fuel phase-outs.

Identifying drivers and barriers as well as mechanisms that lock-in dominant practices improves the understanding of transition mechanisms, like regime resistance, thereby facilitating the development of political strategies to guide and accelerate transitions. Managing successful coal and natural gas phase-outs is an important step for climate change mitigation. The ratcheting-up of climate policy in combination with energy, structural, and social policies tailored to the respective socio-technical, techno-economic and political contexts can facilitate an accelerated decline of coal and natural gas.

Keywords: Energy transitions, climate change, coal phase-outs, natural gas risks, lock-ins, energy economics, political economy, regime resistance

Zusammenfassung

Diese Dissertation befasst sich mit nachhaltigen Energietransformationen, die eine Strategie zur Eindämmung des Klimawandels darstellen. Wirtschaftliche, politische, technische und soziale Aspekte werden kombiniert, um Energietransformationen der verschiedenen fossilen Energieträger Steinkohle, Braunkohle und (Flüssig-)Erdgas zu analysieren. Dabei werden sowohl die Transformationsprozesse des Ausstiegs, des Lock-in als auch des Einstiegs abgedeckt. Weltweit ist die Energiewende noch zu langsam, um Emissionsminderungen in der erforderlichen Größenordnung rechtzeitig zu erreichen. Die Beschleunigung von Nachhaltigkeitstransformationen wird durch fehlende politische und wirtschaftliche Machbarkeit sowie unzureichendes Wissen über Steuerungsmöglichkeiten behindert. Durch die Kombination von Erkenntnissen zu verschiedenen Energieträgern, Transformationsphasen und geografischen Bereichen untersucht diese Dissertation, welche Lehren aus vergangenen und derzeitigen Transformationsprozessen gezogen werden können, welche Mechanismen Lock-ins in Kohle und Erdgas erzeugen, welche Barriere Erdgas für Nachhaltigkeitstransformationen darstellt sowie welche politischen Maßnahmen den Ausstieg aus fossilen Brennstoffen erleichtern können.

Drei Kapitel dieser Dissertation umfassen Fallstudien zu (i) Lehren aus dem historischen Steinkohlebergbau-Ausstieg in Deutschland, (ii) der politischen Ökonomie der Kohlenutzung in Polen und (iii) dem Risiko Deutschlands, mit Investitionen in Flüssiggas-Terminals einen weiteren Lock-in in Erdgas zu erzeugen. Kapitel 5 stellt literaturbasiert systematisch die Risiken und Barrieren von Erdgas für die Energiewende dar. Zusammenfassend stelle ich fest, dass Trägheit und Widerstand gegen einen Kohle- und Erdgasausstieg durch industrielle Akteure, Gewerkschaften, die Zivilgesellschaft und politische Akteure verursacht werden. Weiterhin zeige ich auf, dass es starke technologische und infrastrukturelle, institutionelle, verhaltensbezogene und diskursive Lock-ins von Kohle und Erdgas gibt. Für Kohle werden auf Basis der Analyse des techno-ökonomischen und sozio-politischen Umfelds sowie wirtschaftlicher, sozialer und geographischer Indikatoren Politikempfehlungen abgeleitet, wie der Rückgang der Kohle bewältigt werden kann. Zuletzt ergänze ich den wissenschaftlichen Diskurs zu Erdgas um dessen Rolle in Bezug auf Nachhaltigkeitstransformationen und zeige Mechanismen auf, wie Lock-ins und anhaltende politische Unterstützung für Erdgas entstehen.

Die vier wichtigsten Beiträge zur akademischen Literatur sind (1) ein neuer methodischer Ansatz, der Akteurs- und Materialanalysen zur Untersuchung der Energiewende kombiniert, (2) ein verbessertes Verständnis der starken Trägheit, die dominante Kohle- und Erdgas-Regime für Transformationen erzeugen können, (3) ein systematischer Überblick über die spärliche Evidenz zu den Risiken, die mit der Rolle von Erdgas in Nachhaltigkeitstransformationen verbunden sind, und (4) die Identifizierung von umsetzbaren Politikmaßnahmen für den bevorstehenden Ausstieg aus fossilen Brennstoffen.

Die Identifizierung von Treibern und Barrieren sowie Lock-in-Mechanismen von fossilen Energieträgern verbessert das Verständnis von Transformationsmechanismen wie Regimewiderstand und erleichtert damit die Entwicklung politischer Strategien zur Steuerung und Beschleunigung von Transformationen. Ein erfolgreicher Kohle- und Erdgasausstieg ist ein wichtiger Schritt für den Klimaschutz. Die Verschärfung von Klimapolitik in Kombination mit Energie-, Struktur- und Sozialpolitik, die auf die jeweiligen soziotechnischen, techno-ökonomischen und politischen Kontexte zugeschnitten ist, kann eine Beschleunigung des Rückgangs der Kohle- und Erdgasnutzung ermöglichen.

Schlüsselwörter: Energie Transformationen, Klimawandel, Kohleausstieg, Erdgasrisiken, Lock-ins, Energiewirtschaft, politische Ökonomie, Regime-Widerstand

Acknowledgements

My biggest thank you goes to Prof. Dr. Pao-Yu Oei for making my dissertation possible, and for always making me go one step further than what I thought I was capable of. Thank you for the wonderful balance of guidance and letting me discover my own ways and ideas. I also want to thank Prof. Dr. Christian von Hirschhausen for disputes about *numbers* and *transformations*, as well as his support and trust when it mattered. I am amazed and very grateful to Asst. Prof. Dr. Jessica Jewell for her wonderful way of asking questions, and teaching me how to be more reflective, inquisitive, and precise.

My academic pathway would not have happened without my wonderful start in the scientific research world made possible by Prof. Dr. Franziska Holz, Jun.-Prof. Dr. Philipp Richter, Prof. Dr. Claudia Kemfert, and Dr. Daniel Huppmann. Thank you all for your sharing your experience, and making me feel that a doctorate was actually something feasible.

The whole CoalExit Research Group helped to sharpen ideas, discover interesting insights, and most of all made the last few years a lot of fun. All of you were amazing colleagues, but I want to thank especially Isabell Braunger, for sharing joyful times in one office room while that was still the normal way to work, and the joint efforts to expand *CoalExit* to *GasExit*.

Thanks deserves also Thomas Kouroughli, for the journey, and showing me that the economics profession was much more interesting, diverse and useful than I knew. The STEPS summer school renewed my motivation, and provided me with new insights and some tools for becoming a better researcher. Thank you especially Victoria, Niak, Fatime and Nimisha for sharing your passion, personal stories, and positive energy.

I also want to thank FRT at Chalmers University for making my research stay possible and welcoming me so openly, and especially to Prof. Dr. Christian Azar and Prof. Dr. Tomas Kaberger for debates, excursions, and sharing your knowledge. Further thanks go to all my other friends and colleagues at TU Berlin, DIW Berlin, other research institutes, and NGOs for making work such a motivating, meaningful, and lively place to be.

Thank you Nils Ohlendorf, for an always open ear, instant proof reading, and delightful conversations to develop new narratives. The end would have been so much harder without you. Without my parents, none of this would have been possible. Thank you for your limitless support. Lastly, I want to say thank you to Lea, Lisa, Lotte, Christoph, Mara and Cleo from *Togohausen,* for always cheering me up and providing wonderful distractions during home office life.

Rechtliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Dissertation selbstständig und ohne unzulässige Hilfsmittel verfasst habe. Die verwendeten Quellen sind vollständig im Literaturverzeichnis angegeben. Die Arbeit wurde noch keiner Prüfungsbehörde in gleicher oder ähnlicher Form vorgelegt.

Hanna Brauers

Berlin, 29.06.2021

Overview

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List of Abbreviations

bcm	billion cubic meters
CME	Coordinated Market Economy
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DIW Berlin	German Institute for Economic Research
DUH	Deutsche Umwelthilfe (Environmental Action Germany)
DVGW	German Technical and Scientific Association for Gas and Water
ECSC	European Coal and Steel Community
EEG	German Renewable Energy Act
EVU	Energy, Transportation, Environment (DIW Berlin)
EU	European Union
FRT	Physical Resource Theory (Chalmers University)
FSRU	Floating Storage Regasification Unit
GEG	Gross Electricity Generation
GHG	greenhouse gas
GRW	Joint Task for the Improvement of Regional Economic Structures
GWP	Global Warming Potential
IAMs	Integrated Assessment Models
IPCC	Intergovernmental Panel on Climate Change
LNG	Liquefied Natural Gas
MTPA	million tons per annum
NECP	National Energy and Climate Plan
NG	Natural Gas
NGOs	Non-Governmental Organisations
PEC	Primary Energy Consumption
PPCA	Powering Past Coal Alliance
TEF	Triple Embeddedness Framework
WBGU	German Advisory Council on Global Change
WIP	Workgroup for Infrastructure Policy (TU Berlin)

Chapter 1

Introduction:
Energy transitions, climate change & political economy

1 Introduction

'Economics is the mother tongue of public policy, the language of public life, and the mindset that shapes society' (Raworth 2017, 6).

'Climate change is a political choice' (Smyth 2015).

1.1 Motivation

Limiting climate change is one of the main societal challenges (Hasselmann et al. 2003; IPCC 2014). My concerns about climate change had – long before I started my dissertation – impacted decisions I made regarding what I wanted to learn and work for. The fascination for scientific work came with my research assistant job at the Department of Energy, Transportation, Environment (EVU) at the German Institute for Economic Research (DIW Berlin) in 2013. I was lucky enough to meet four special people there, all of whom took care to teach me how to do research and continuously encouraged me to learn more, as well as to consider a doctorate. The seemingly simple step of doing an internship at DIW Berlin in 2013 created a strong path dependency: The task to support a project on the security of European natural gas supply and getting the chance to investigate the process of international climate negotiations resulted in my first publications and a strong interest for natural gas (Richter and Brauers 2015; Brauers and Richter 2016; Holz et al. 2017).

Due to my work at DIW Berlin, I met Pao-Yu Oei and learned about his research on coal phase-outs. I decided to write my Master's thesis on coal under his supervision at the Workgroup for Infrastructure Policy (WIP) at Technische Universität Berlin. Supported by Professor Oei, my academic path continued seamlessly within the DIW Berlin and WIP bubble, resulting in this dissertation on natural gas and coal transitions in the context of climate change mitigation.

Coal and natural gas cause most of the global anthropogenic greenhouse gas (GHG) emissions: Coal was the single largest contributor, with 42% of global CO_2 emissions from 2009-2018 (44% of global CO_2 emissions in 2018), and CO_2 emissions related to natural gas had the largest growth rates with 2.6/year between 2009-2018 (Peters et al. 2020; IEA 2021). Additionally, coal and natural gas are responsible for a large share of global anthropogenic methane emissions: From 2008–2017, the oil and natural gas sectors were responsible for about 63% of total fossil methane emissions and coal mining for about 33% (Saunois et al. 2020). In the energy sector, coal and natural gas supply the largest share of energy.[1] In 2018, coal provided 27% and natural gas 23% of total primary energy supply globally (IEA 2020c). Together, the potential GHG emissions from already developed reserves of coal and natural gas are larger than the remaining carbon budget left for a 50% chance to reach the 1.5°C target (GGON 2019). Furthermore, if all currently planned coal-fired power plants were built and run, they alone would use almost the entire remaining carbon budget for reaching the 2°C target (Edenhofer et al. 2018). Hence, to achieve climate change mitigation targets, the use of coal and natural gas must be drastically reduced.

[1] Next to oil, which, however, is used more in the transport sector.

Which aspects impede such a reduction and how it can be managed is a focus of energy transition studies. Transitions research is particularly useful in this regard as it enables the combined analysis of economic, political, technical, and social aspects (see e.g. Markard, Raven, and Truffer 2012; Cherp et al. 2018; Köhler et al. 2019). Energy transitions imply that incumbent actors and practices are increasingly challenged, which leads to resistance by those who profit from the status quo (Turnheim and Geels 2012; 2013; Geels 2014c; Kungl 2015; Kungl and Geels 2018; Markard 2018; Sovacool, Turnheim, et al. 2020). Rapid changes can additionally cause negative impacts for societal actors, such as job losses and increasing energy prices, also creating opposition (Spencer et al. 2018; Muttitt and Kartha 2020). Thus, so-called "just transition" approaches combine climate change with structural policies aimed at alleviating social problems incorporating energy, environmental, and climate justice concepts (Rosemberg 2010; ILO 2015; Heffron and McCauley 2018). Potential opposition is particularly important when planning for intentional phase-outs, where political feasibility must be taken into account (Jewell and Cherp 2019; Jewell et al. 2019).

The starting point of my dissertation was to analyse how coal and natural gas phase-outs can become a feasible option. What motivated me to work on this was seeing that research conducted at WIP and the CoalExit research group was always meant to be policy relevant and close to real world developments. This became clear due to the close policy contact in projects with the German Environmental Ministry and Federal Environmental Agency as well as by visiting coal mines in Germany, Poland, and Colombia, natural gas production fields in the Netherlands, and planed sites for Liquefied Natural Gas (LNG) terminals in Germany, as well as numerous exchanges with a diverse range of stakeholders. My work as a research associate led to a few other publications besides the dissertation itself: These include reports on the German coal phase-outs and an overarching report on the status of hard coal and lignite production and use in Germany (Brauers, Herpich, and Oei 2018; Brauers et al. 2018; Oei et al. 2018; DIW Berlin, Wuppertal Institut, and Ecologic Institut 2019), contributing to the development of Chapter 2 of this dissertation. Further publications not directly related to any chapter comprise a book review on the "Doughnut Economics" by Kate Raworth (Brauers and von Hirschhausen 2018) and a scientific policy advice report on the European Green Deal (Hainsch et al. 2020). Of my two other peer-reviewed papers, one compares the coal phase-outs of the United Kingdom and Germany (Brauers, Oei, and Walk 2020), while the other discusses the implications of diversity for global uniform carbon pricing (Verbruggen and Brauers 2020). The process to develop the research questions of Chapter 4 was supported by a working paper on the destabilising effect of natural gas on sustainable energy transitions in Germany (Fitzgerald, Braunger, and Brauers 2019). Lastly, a Scientists for Future report on natural gas (Brauers et al. 2021) includes findings from Chapters 4 and 5.

Especially important for my academic development were ideas and perspectives from two visitations to new and quite distinct environments: A two-week Summer School on Pathways to Sustainability at the STEPS Centre (Sussex University; United Kingdom), with its diverse participants, topics, and approaches, as well as a two-month research stay at the Physical Resource Theory (FRT) Division at Chalmers University in Sweden. FRT affected me significantly: My thinking was challenged there, as it had never been before – never in a discouraging but always in a supportive and inspiring way – with three people providing me with their kind and helpful support. WIP, STEPS, and FRT all have very different stances on how to do research and, in particular, how to use and promote research results – spanning from the open calls for academic activism to neutral science where a researcher should not aim to influence the policy sphere. I learned a lot from all these perspectives, aiming to find my own path somewhere in between.

During the time of my dissertation, Germany went through the process of deciding on a coal phase-out pathway. It was encouraging to see how the wealth of studies on coal at WIP – above all from Prof. Dr. Pao-Yu Oei and Prof. Dr. Christian von Hirschhausen – was included in the decision process (Gerbaulet, Egerer, Oei, Paeper, et al. 2012; Gerbaulet, Egerer, Oei, and Hirschhausen 2012; Hirschhausen and Oei 2013; Oei et al. 2014; 2016; Oei, Brauers, Kemfert, von Hirschhausen, et al. 2017; Göke, Kittel, Kemfert, Lorenz, et al. 2018; Oei et al. 2018; DIW Berlin, Wuppertal Institut, and Ecologic Institut 2019; Stognief et al. 2020). Being given some unusual opportunities by the CoalExit network myself, my motivation was boosted by meeting two of the most visible civil society personalities fighting against climate change in Germany: I had the chance to share some of my research insights for a BBC documentary on coal with Greta Thunberg at the largest coal mine in Europe – shortly before the global pandemic stopped meetings and travel – and to have a Scientists for Future meeting on the climate impacts of natural gas with Luisa Neubauer – already in the new videoconference world.

What remains to say is that a dissertation like this would not have been possible without the amazing network of the CoalExit research group, the WIP, and the EVU. Despite all of this being my own intellectual work, it would simply not have been feasible without the personal support, the contacts to other researchers, institutions, and networks, as well as the general inspiring environment of ambition and passion for cutting edge and meaningful research.

My research assumes that climate protection targets, above all set out in the Paris Climate Agreement (UNFCCC 2015), are to be fulfilled. The main tension field my dissertation tackles is between the political goal to (1) limit climate change to less than 2°C, aiming at 1.5°C, which would (2) challenge current energy and economic systems based on coal and natural gas, and (3) the resulting difficulty to find governance approaches to provide a just transition. Aiming to engage in the debate around transitions motivated by climate change, this dissertation assesses questions related to the phase-outs of coal and natural gas in various countries. It aims to improve the understanding of factors hindering energy transitions, and how such transitions can be accelerated. The analyses focus on the transition processes of phase-out, lock-in, and “phase-in”, different energy carriers, namely hard coal, lignite, and (liquefied) natural gas, as well as three different geographic scopes, namely Germany, Poland, and global. Figure 1-1 summarises the overarching thematic focus of this dissertation.

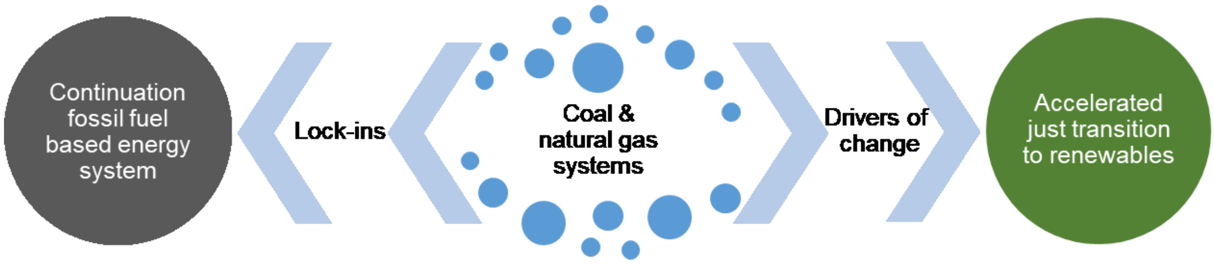

Figure 1-1: Overview thematic focus.

Globally, energy transitions, and, in particular, the phase-out processes of fossil fuels, are still too slow to achieve emission reductions at the required magnitude to comply with internationally agreed climate targets. To design effective coal phase-out strategies, further evidence is needed on which approaches have worked well in past transitions and which ones have failed. The insufficient scale and speed of transitions are also due to strong lock-in mechanisms that may delay or inhibit transitions. However, it is not yet fully understood where different types of lock-in originate from, what specific roles different actors play in creating lock-ins, and how these lock-in mechanisms take effect in different contexts. In addition, it requires further research on the specific consequences lock-ins may have for climate protection ambitions in case they remain unaddressed and how such lock-ins can be overcome. This is particularly the case for natural gas, where the impact of an increasing use of natural gas and its general role in accelerating sustainability transitions[2] is still poorly understood. Guided by these research gaps, this dissertation specifically analyses i) what lessons can be learned for upcoming transitions from past phase-outs and ongoing transition processes; ii) what mechanisms create lock-ins into coal and natural gas; iii) what barrier natural gas poses to sustainability transitions; and iv) which policy measures can help to address lock-ins and to facilitate the phase-outs of fossil fuels.

This dissertation contributes to the sustainability transitions literature in four main ways: (1) It develops a new approach on how to combine actor and material analyses, applying it, alongside selected (meta-)theoretical transition frameworks, to novel empirical cases to foster the understanding of energy transitions. (2) It improves the understanding of the effects that dominant regimes around coal and natural gas can have on transitions and the powerful inertia it can create. (3) It adds to the emerging and, thus far, understudied topic of natural gas lock-ins by highlighting the set of barriers and risks to energy transitions. (4) Finally, it contributes to the identification of feasible transition and governance strategies for upcoming phase-outs by identifying benefits and risks as well as drivers and barriers for change.

[2] Sustainability transitions are a subset of socio-technical transitions that are associated with sustainability targets and guided by public policies as a response to “grand challenges” such as climate change. Based on a review by Markard et al. (2012), this dissertation uses the following definition of “sustainability transition”: A sustainability transition comprises far-reaching changes of the institutional, organisational, technical, social, and/or political aspects of existing socio-technical systems, related to more sustainable or climate-friendly modes of production and consumption. In several Chapters, the terms “transition” and “transformation” are used interchangeably. Differences in the meanings of the two terms exist in the literature, e.g. with regard to a stronger focus on societal contributions to change oftentimes used in the transition literature, or bottom-up “transformations” rather than top-down “transitions”; the term “transformation” also sometimes comprises comprehensive social upheavals (Child and Breyer 2017).

The remainder of this opening chapter introduces the research fields, theories, and concepts on which this dissertation is built. It starts with the field of energy transitions research (Section 1.2), continues with the economics of climate change and energy (Section 1.3), and the relation with political economy (Section 1.4). After introducing the main methods and frameworks used (Section 1.5), a detailed outline of the dissertation introducing the main body of four chapters of original research articles (Section 1.6) is followed by some concluding remarks (Section 1.7). The four other dissertation chapters focus on the lessons of the historical hard coal mining phase-out in Germany (Chapter 2), the political economy related challenges of Poland to reduce its coal use (Chapter 3), the risk of Germany creating a further lock-in into natural gas with LNG terminal investments (Chapter 4), and, lastly the systematic mapping of risks natural gas poses for energy transitions (Chapter 5).

1.2 Energy transitions research

The focus of this dissertation is on energy transitions, as one part of climate change mitigation strategies. Due to the extraordinary scope and complexity of questions related to energy and climate change, “sustainability science” and transitions research is now a major research field (Grubb, Hourcade, and Neuhoff 2015). Rooted in energy transitions research, this dissertation analyses different transition phases using several transitions frameworks and concepts such as regime resistance, just transitions, and lock-ins, briefly explained in the following.

Transitions can be seen as interpretive, politically contested, and conflictual processes. Socio-technical transitions are characterised as evolutionary processes, which means that they are open-ended, non-linear, and fundamentally uncertain (Markard, Raven, and Truffer 2012; Fünfschilling and Truffer 2014; Cherp et al. 2018; Kern and Rogge 2018; Geels 2020). The most prominent theoretical frameworks in the transitions literature encompass the multi-level perspective, transition management, strategic niche management, and technological innovation systems (Markard, Raven, and Truffer 2012; Fünfschilling and Truffer 2014). However, they have been criticised for focusing mainly on the early stages of transitions and not engaging sufficiently with the political processes of accelerated ones (Roberts and Geels 2019). To analyse the influence of dominant regimes and the potential acceleration of transitions, the Triple Embeddedness Framework (Geels 2014a) and a meta-theoretical energy transitions framework (Cherp et al. 2018) are particularly useful, and are applied in Chapters 3 and 4.

The transitions literature includes several terms and concepts that warrant explanation: First, technologies are conceptualised as socially constructed and not simply developing by an internal technical logic. Often, change is seen as created by innovative niches challenging current regimes. The regime is represented by a relatively stable, aligned, and shared set of rules and routines embedded in socio-technical systems, like current structures and practices, that direct the behaviour of actors. A regime is characterised by lock-in and path dependence. While niches are characterised as the space where radical innovations can emerge, regimes are oriented toward incremental innovation along predictable trajectories (Geels 2010; Kanger and Schot 2019; Cherp et al. 2018; Geels 2020). An incumbent actor or institution is part of a regime and has vested interests in maintaining the status quo instead of enabling change and transition. Incumbents ‘tend to be powerful, materially resourceful, politically influential, societally authoritative, strategically conservative and risk-averse’ (Sovacool, Turnheim, et al. 2020, 3), and often act strategically to protect their privileged position (Geels 2014c; Johnstone, Stirling, and Sovacool 2017; Sovacool, Turnheim, et al. 2020). The influence of regimes on how transitions unfold and the resulting need to take this influence into account when planning transition strategies is part of all subsequent chapters in this dissertation.

A struggle between a niche and an existing regime could, for example, involve business struggles between new market entrants and incumbents, new and old technologies, discursive conflicts about what actually constitutes a problem and what therefore might be solutions, or political struggles about the best goals or policies. Transitions continuously evolve and are contested between a variety of actors (Avelino and Wittmayer 2016; Geels 2020). Generally, to persist, organisations cannot only strive for economic efficiency. Due to their embeddedness in institutional environments, they must also compete for social fitness, which means perceived appropriateness or legitimacy by society or policy actors (Geels 2020).

Relevant actors typically included in transitions research, due to their impact on transition paths, are firms, consumers, state actors, regulatory agencies, lobbying and advocacy groups, unions, as well as social pressure groups (Beckert 2010; Fischer and Newig 2016). Actors generally have different interests, goals, (financial) resources, and interpretations (Fünfschilling and Truffer 2014; Avelino and Wittmayer 2016; Avelino 2017). Institutions are highly institutionalised structures, such as policies but also standards, rules, and values (Fünfschilling and Truffer 2014). Institutions typically influence actors and, inversely, actors also shape institutions; hence, a recursive interaction between agency and structure exists (Geels 2020). A focus on identifying the most relevant and influential actors, as well as an analysis of their interests, strategies and impact on the respective transition processes is carried out in Chapters 2, 3, and 4.

Energy transitions can be analysed by combining three main perspectives, the techno-economic, socio-technical, and political perspective (Cherp et al. 2018). The techno-economic perspective has its disciplinary roots mainly in economic history, neoclassical, evolutionary, and ecological economics as well energy systems analysis. The socio-technical perspective is rooted in sociology and the history of technology, Science and Technology Studies, and evolutionary economics, while the political perspective is based on disciplines such as political science, political economy, policy studies, and international relations (Cherp et al. 2018).

Much of the existing socio-technical literature focuses on how niches can be supported so that they can challenge the regime (Kemp, Schot, and Hoogma 1998; Carlsson et al. 2002). Increasingly, transitions research with a focus on socio-technical and political aspects also deals directly with incumbency, exnovation, and deliberate decline (Turnheim and Geels 2012; Kivimaa and Kern 2016; Rogge and Johnstone 2017; Johnstone, Stirling, and Sovacool 2017; Heyen, Hermwille, and Wehnert 2017; David 2017; Rosenbloom 2018; Rentier, Lelieveldt, and Kramer 2019; Jewell et al. 2019; Rosenbloom and Rinscheid 2020). However, although a few strands of research are analysing the governance of deliberate decline, its role is still poorly understood (Rosenbloom and Rinscheid 2020).

Most historical energy transitions emerged and evolved due to undirected changes. Current and future sustainability transitions might be accelerated when they are deliberately pushed and guided by governments and other powerful actors. Relevant in this context is to analyse which intervention strategies are useful in supporting niches and in phasing-out unsustainable infrastructure and practices, but also the feasibility of implementation especially in the context of resistance by incumbents (Kern and Rogge 2016; Sovacool and Geels 2016; Roberts and Geels 2019). While Chapters 2 and 3 analyse coal phase-outs and related regime resistance as well as intervention strategies, Chapter 5 discovers regime resistance of natural gas actors in the context of a coal phase-out and a generally accelerating energy transition.

One strand of the energy transitions literature targets so-called “just transitions”. The concept of “just transition” originates from the trade union movement, linking climate policy to employment (ITUC 2007; ILO 2015). Incorporating both structural policy and climate dimensions is an important aspect of the so-called “just transition” concept, which specifically targets local job prospects and alleviating social problems of workers and their families (Rosemberg 2010; ILO 2015). Other concepts target the far-reaching consequences of fossil fuel consumption beyond the concerns of workers at the regional level, aiming at a global and holistic perspective, focusing specifically on a transition away from fossil fuel-based economies. Justice in this context is characterised as distributive, procedural, and recognition justice (Sovacool et al. 2016; Pellegrini-Masini, Pirni, and Maran 2020), as well as by the ten principles to achieve justice: availability, affordability, due process, transparency and accountability, sustainability, intragenerational equity, intergenerational equity, responsibility, resistance, and intersectionality (Sovacool et al. 2017). Highlighting energy injustices can be seen as one approach to examine the full costs of fossil fuels (Healy, Stephens, and Malin 2019). In the following, a just transition is defined to subsume energy, environmental, and climate justice (Heffron and McCauley 2018). Chapters 2 and 3 focus not only on a transition to renewable energies, but specifically on just transition opportunities.

Especially concerning coal, a broad range of transition studies exists (Diluiso et al. under review). Other transitions research with regards to coal and natural gas specifically focus on the opportunities and challenges of just coal phase-outs (Abraham 2017; Mayer 2018; Green and Gambhir 2019) and more broadly on just transition aspects of coal and natural gas exits (Muttitt and Kartha 2020). Another focus is the debate on the option of a coal-to-gas switch, how this can be achieved, but also whether this makes sense from a climate perspective (Lueken et al. 2016; Knittel, Metaxoglou, and Trindade 2016; Gilbert and Sovacool 2017; Wilson and Staffell 2018; Coulomb, Lecuyer, and Vogt-Schilb 2019). As natural gas seems to be much less covered than coal in transitions research, Chapter 5 set out to review existing literature on natural gas phase-outs and identifies climate, techno-economic and social risks as well as related political challenges.

1.3 The economics of climate change and energy

Energy’s crucial role for development, human well-being, and economic prosperity (P. Newell and Paterson 1998) has made the field of energy economics very important. The energy transitions literature includes a wide variety of classical but also heterodox economic theories. The socio-technical literature sometimes positions itself as contrary to that of neo-classical economic theory (Cherp et al. 2018). Transition studies enable the inclusion of economic theories and techno-economic aspects, while taking a more holistic approach as it links them to social and political ones. In the following, classical and neoclassical approaches to climate and energy economics are discussed to show how transitions research can build on their results and constitutes an important extension to analyse phase-outs of fossil fuels.

Based on classical, neoclassical and Hayekian logics, markets gained a dominant role in contemporary mainstream economic thought and policy. Such economic approaches mostly aim to optimise markets (Grubb, Hourcade, and Neuhoff 2015). With regards to the economics of climate change, many modelling efforts have been conducted to estimate the economic costs and benefits of climate change mitigation (Nordhaus 1991; N. Stern 2007; IPCC 2014; Diaz and Moore 2017). Generally, the cost calculations in such models depend to a large extent on the discount rate and on how costs in regions that are poorer or wealthier are aggregated into a global cost estimate (Azar and Sterner 1996). The social discount rate alone has long caused disagreement between economists (prominently between Stern (2007) and Nordhaus (2008) and subsequent scientific and political debates), resulting in widely diverging appropriate levels of climate change mitigation (Weitzman 2011; Drupp et al. 2018; Hänsel et al. 2020). Assumptions made on so called utility and welfare functions have a large impact on model results and are essentially value judgements. Economic analyses are not – despite frequent claims to the contrary – value free or a neutral scientific method, and there are calls to highlight these value-laden choices transparently (Azar and Sterner 1996; Azar 1998; Nelson 2013; Martínez Alier and Muradian 2015).

Despite such existing disagreement about model assumptions, values, and transparency, modelling efforts show concurringly the need to rapidly phase out the use of coal and natural gas to achieve climate change mitigation targets (IPCC 2014; J. Rogelj et al. 2018; Joeri Rogelj et al. 2019; Löffler et al. 2019; Auer et al. 2020).

To take stock of emissions and to evaluate their potential impacts is the first step in these modelling efforts on climate change mitigation. National GHG accounting is complicated by the choices of which emissions to account for and which metrics to apply. In particular, whether only traditional territorial emissions inventories are used or whether instead emissions along the entire value chain are accounted for affects how well the global impact on the climate is captured. The gap between production and consumption based accounting can be closed further when non-CO_2 emissions are included as well (R. Wood et al. 2020). This is especially important in the context of methane emissions related to natural gas use during the production and transport stages, having a large impact on the overall estimated climate impact (Alvarez et al. 2012; Hausfather 2015; Zhang et al. 2016; Alvarez et al. 2018), which is more extensively discussed in Chapters 4 and 5.

Along the lines that energy economics needs to explicitly deal with finite energy supply and resource stocks, articles and books about the limits to growth and the true costs of growth are a long-standing important part of the economics field (Meadows et al. 1972; Daly 1980). There are more recent calls for a more holistic linkage of economics with energy, climate change, sustainability, and human well-being (Raworth 2017; Jackson 2017). This dissertation aims to incorporate the lessons from this broader approach to economic thinking.

One aspect deeply influencing energy transitions, but often only considered from a purely techno-economic perspective, are stranded assets: Energy infrastructures typically have lifetimes of several decades, with existing coal and natural gas infrastructure related to large amounts of committed GHG emissions. If the targets of the Paris Agreement are adhered to, much of this infrastructures would need to be decommissioned prematurely, resulting in financial losses – so called stranded assets. Estimates suggest that even if all newly planned power plants were cancelled, ~20% of global power plant capacity would need to be stranded (Pfeiffer et al. 2018). The calculations of committed emissions are sensitive to the assumed operating lifetimes and schedules, as well as the economic value of the infrastructure (Tong et al. 2019). However, although the exact value of stranded assets is uncertain, history shows that it creates resistance among those actors losing their profits and, therefore, by policy actors concerned about such resistance or the potential need for compensation (Serkin and Vandenbergh 2018). The used transitions research frameworks can cover stranded assets from both the techno-economic and political perspectives. Stranded asset risks and resulting regime resistance are covered in all following chapters.

The most discussed economic policy tool to regulate climate change are various forms of carbon pricing (Ockenfels, Werner, and Edenhofer 2020; Jakob, Lamb, et al. 2020). However, carbon pricing alone might not be sufficient to achieve deep decarbonisation and risks resistance. Thus, it should be complemented by other instruments in a case specific policy mix (Grubb, Hourcade, and Neuhoff 2015; Hepburn, Stern, and Stiglitz 2020; van den Bergh and Botzen 2020; Rosenbloom et al. 2020). A policy mix for a phase-out can, for example, include the specification of the power plant retirement sequence, inclusion of key stakeholders in the process, and supporting alternative regional economic opportunities (Jakob, Steckel, et al. 2020).

Pure economic pressures, such as uneconomic coal mines, are proven insufficient to achieve phase-outs. *Innovation* and fostering the 'niche' of renewable energies is necessary, but not sufficient, for achieving global or national climate change mitigation targets and must be combined with e*xnovation* and phase-outs of fossil fuels (Turnheim and Geels 2012; Kivimaa and Kern 2016; Kern and Rogge 2016; Rogge and Johnstone 2017; Heyen, Hermwille, and Wehnert 2017; David 2017; Davidson 2019). Coal and natural gas phase-outs need to be targeted specifically by energy, climate, and structural policy instruments to achieve emission reductions on the required scale, on the one hand, as well as to manage the related economic and social consequences, on the other hand. Therefore, it is important to combine economic analyses with political ones when investigating fossil fuel phase-out processes.

1.4 Political economy and policy aspects

Energy systems are highly regulated and influenced by government policies since at least the industrial revolution (Grubb and Neuhoff 2006). Not only policies but politics in general impact energy sector developments greatly (Pierson 1993; Stirling 2014). The energy transitions literature is criticized in the past for not focusing sufficiently on political processes, especially in the context of accelerating transitions (Meadowcroft 2009; Roberts and Geels 2019). Increasingly, political and political-economy approaches play a larger role in sustainability transitions research (Kern and Rogge 2018). Political economy plays an important role in phase-outs of coal and natural gas. Therefore, this section introduces important concepts of political economy and explains in what ways they were included in this dissertation.

Political economy was once a goal-oriented science (Adam Smith (unspecified) in Raworth (2017, 33)). Traditionally, it was concerned with scarcity and the resolution of social conflicts. A focus was put both on the ends and the means of how to achieve those ends (Daly 1980). The field of political economy has, since the 18th century, evolved and morphed into a variety of streams based on different theories and methods. Generally, a political economy perspective can help, as 'the essence of economic processes is lost if one treats the economy in isolation from its social and institutional context' (Gustav Schmoller (unspecified) in Milonakis and Fine (2009, 82)). Hence, economic facts and theories need to be interpreted in the context of place, time, and respective society. They should not be seen as a timeless, causal law. Milonakis and Fine end their historical analysis of the evolution of (political) economics since the 1870s by illustrating that different views exist on what contemporary political economy consists of today and that it is open for alternative, especially interdisciplinary, approaches (Milonakis and Fine 2009).

The political economy factors related to coal and natural gas phase-outs and lock-ins included in this dissertation include, among others, the dependence of regional and national governments on tax revenues from fossil fuel extraction, share of fossil revenues in gross domestic products, governments dependence on voter support that can be harmed by economic downturns or increasing unemployment rates, as well as other influencing aspects such as vested interests by corporations and the political power of corporate interests' groups, unions, and other actors. A particularly interesting case connecting the private and public spheres of political economy are state-owned energy corporations (see Chapter 3). A political economy perspective opens up the view from single challenges, policy goals or economic factors, to the interaction of policies and politics with techno-economic and socio-technical aspects.

To identify feasible transition pathways, it is important to consider what is politically feasible. Political feasibility can be defined in different ways (Majone 1975; Gilabert and Lawford-Smith 2012; Lawford-Smith 2013). Generally, a proposal is feasible if it can meet all relevant constraints (e.g. technical, economic, legal, administrative, etc.) (Majone 1975). Sometimes, desirability of a policy option is mistaken for feasibility. However, oftentimes the costs of a required action – e.g. to phase-out fossil fuels – are too high in relation to the capacities of the relevant actors to bear the costs (Jewell et al. 2019). Therefore, the following concept of political feasibility is used in the following: To understand whether something is politically feasible in a specific context requires to answer three questions: (1) Feasibility of what, (2) feasibility when and where, and (3) feasibility for whom (Jewell and Cherp 2019). This conceptualisation encompasses that over time the costs of an option can decrease (or increase) and the capacities of actors can change, opening up a dynamic political feasibility space for a specific context (Jewell and Cherp 2019). This conceptualization also highlights that political actions to achieve coal or natural gas phase-outs can be rendered infeasible by constraints outside of the control of actors, which makes the analysis of both material conditions and actors important.

One such constraint is that mitigating climate change is likely to create conflicts within societies and have distributional consequences, critically also with disproportionate impacts on certain vulnerable groups (N. Wood and Roelich 2019; Meadowcroft 2009). Hence, a focus on justice aspects related to climate change is important (Creutzig et al. 2014; Sovacool et al. 2016; N. Wood and Roelich 2019; Healy, Stephens, and Malin 2019; Pellegrini-Masini, Pirni, and Maran 2020). Modern energy justice problems arise, for example, as the costs of implementing climate change mitigation policies are not distributed equally across individuals in a society or across societies. Due to resistance resulting from negative economic consequences, climate policy is sensitive to compensation payments of certain groups and the provision of new employment opportunities (Tvinnereim and Ivarsflaten 2016). An advantage of transitions research is that it can link the pure economic distributional effects with the resulting responses of actors. Chapters 2 and 3 cover just transition aspects and structural change impacts related to coal phase-outs in detail, while resistance to energy transitions and related phase-outs are covered in all the chapters.

The concept of regime resistance is relevant to energy transitions and connects different political economy aspects: When an incumbent regime of actors and institutions benefits from a continued reliance on fossil fuels, resistance to change arises (Geels 2014c; Lockwood, Mitchell, and Hoggett 2019). For example, states that benefit from revenues generated by fossil fuels are unlikely to initiate change (P. Newell and Paterson 1998). Thus, regime actors use their material, institutional, and discursive power to prevent disruptive changes in socio-technical configurations, social relations, and distributions of political power (P. Newell 2018). Regime resistance is covered in all dissertation chapters.

Intertwined with the above are other important concepts greatly influencing coal and natural gas transitions, namely path dependency and lock-ins: ‘Path-dependent processes are those that develop inertial resistance to large-scale systematic shifts’ (Seto et al. 2016, 426). Resistance is caused when existing social, political and economic conditions are beneficial for powerful actors and increasing returns to scale exist (Erickson et al. 2015; Seto et al. 2016). Once technologies with a long lifetime are built and, due to technological and institutional co-evolution, become entrenched in the current system, they are difficult to change (Unruh 2000). One phenomenon of path dependence is carbon lock-in. The term ‘carbon lock-in’ refers to the tendency of carbon-intensive socio-technological system to remain that way, thereby locking-out lower-carbon alternatives (Unruh 2000; Erickson et al. 2015). Due to large capital costs, long infrastructure lifetimes, as well as the strong interrelationships between political, techno-economic, and socio-technical systems, carbon lock-in is particularly prone to entrenchment (Seto et al. 2016). An analysis looking at major energy-consuming assets in the power, buildings, industry, and transport sectors find that the largest carbon lock-ins are for coal and natural gas (Erickson et al. 2015).

Further investments in assets prone to carbon lock-in – such as coal and natural gas infrastructure – limit future flexibility, create persistent market and policy failures, and increase the costs of achieving climate change mitigation targets (Unruh 2000; Erickson et al. 2015). The main risk is that what was intended to be a temporary solution becomes permanent and entrenched. A reliance, for instance, on natural gas, in turn, hinders deeper societal change toward low-carbon societies (Castán Broto 2018). Seto et. al (2016) identifies three main types of carbon lock-in: (a) infrastructural and technological; (b) institutional; and (c) behavioural lock-in. For example, infrastructure lock-in is characterised by not just by technological and economic forces leading to inertia, but also that the initial choices do not include social costs and benefits besides the private ones. Institutional lock-ins are characterised by powerful actors seeking to protect the status quo as it favours their interests. This is helped by the fact that institutions are generally designed to be stable. Behavioural lock-in exists mainly due to social structures, like norms and other social processes, as well as the difficulty of changing existing habits (Seto et al. 2016). A fourth type of lock-in connecting the former three is newly identified: (d) *discursive lock-in.* ‘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). A dominant discourse can constitute and justify institutions, technologies, and behaviours (Buschmann and Oels 2019). These four types of lock-in can be used to understand the full carbon lock-in potential and related risks of coal and natural gas. These are analysed explicitly in Chapters 4 and 5, while Chapters 2 and 3 touch upon carbon lock-in more generally.

Discourses and ideas play an important role in policy analyses and are increasingly tackled in the analyses of sustainability transitions (Rosenbloom 2018). The way actors understand social and physical realities can influence how these are discussed and perceived by society. Reciprocally, a discourse is both enabled and constrained by the specific context (Hajer 1995). Framing a problem or a solution in a certain way can serve an important strategic function for actors to actively influence policy issues to privilege their own interests. In transition processes, discourses can be strategically leveraged by actors to maintain or disrupt a specific socio-technical system configuration (Rosenbloom 2018). The related struggles over ideas – but also more generally values – are particularly relevant when the uncertainty of a transition path is high, and framings are highly contested (Isoaho and Markard 2020). Hence, phase-out processes are not just conflicts over economic interests. They are influenced by struggles over different ideas and societal norms, as well as what in the public and political discourse is considered as suitable and legitimate (Isoaho and Markard 2020). Discourses that are used to create support for both coal and natural gas often used the “bridge fuel” metaphor (Delborne et al. 2020). The influence of the bridge discourse on the developments regarding natural gas is highlighted in Chapters 4 and 5, while Chapter 3 highlights discourses on coal regarding the economic dependence on mining, energy security, air pollution, and “clean” coal.

The dissertation builds on a wealth of other political economy analyses, especially regarding coal. Rentier, Lelieveldt, and Kramer, for instance, focus on the identification of strategic interaction amongst relevant stakeholders influencing the direction and speed of European coal transitions, as well as how compensation payments are used to achieve agreement of negatively affected stakeholders (Rentier, Lelieveldt, and Kramer 2019). Another particularly interesting case for political economy analyses regarding coal is the formation of the Powering Past Coal Alliance (Jewell et al. 2019; Blondeel, Van de Graaf, and Haesebrouck 2020). Discursive analyses cover both coal (Rosenbloom 2018; Leipprand and Flachsland 2018; Isoaho and Markard 2020; Müller-Hansen et al. 2021) and natural gas (Bosman et al. 2014; Delborne et al. 2020). Political economy analyses of natural gas in Europe often take an energy security perspective (Westphal 2014; Szulecki et al. 2016), which is why Chapter 4 and the analysis of natural gas in Germany can be seen as covering an important literature gap with regards to the political economy of natural gas in the context of energy transitions.

Further, the dissertation contributes to the understanding of the role governments play in intentional transition processes. Chapter 2 analyses 60 years of national and sub-national level government policies targeting the hard coal industry, regions, and workers in Germany. It shows how the government deliberately slowed down the reduction of coal mining and use, but also simultaneously softened related negative social impacts. Chapter 3 studies the special role the Polish national government plays in protecting its coal industry and illustrates the strong links between the policy makers, industry, and unions protecting the coal sector. Chapter 4 provides an in-depth analysis of the political support LNG terminal proposals receive in Germany, again highlighting the web of actors and interests leading to such support. Chapter 5 shows the governmental challenges related to natural gas in different sectors and constituencies. Taking the dissertation chapters together, they cover the wide array of political challenges related to different transition processes, energy carriers, and geographic scopes.

1.5 Methods and frameworks

The main methods, frameworks and concepts used in this dissertation are summarised in Table 1-1. In the following, a brief introduction to them is given, where the chapters themselves did not offer enough space to explain them, or it helps to understand the connection between chapters.

Table 1-1: Methods and frameworks of each chapter.

	Chapter 2	**Chapter 3**	**Chapter 4**	**Chapter 5**
Framework	Typology of substantive transition policy options (Spencer et al. 2018)	Triple Embeddedness Framework (Geels 2014a)	Meta-theoretical energy transition framework (Cherp et al. 2018)	-
Methods	Historical and comparative political economy analysis of two case studies (the hard coal regions Ruhr and Saarland in Germany)	Case study analysis based on material analysis of documents as well as workshop participation and background interviews	Case study based on semi-structured interviews, background talks and workshop organisation; qualitative content analysis and combination of actor and material analysis	Systematic literature mapping

1.5.1 Main frameworks

In this dissertation, three different lenses, in the form of typologies and frameworks, are applied. The typology of substantive transition policy options (Spencer et al. 2018), the Triple Embeddedness Framework (Geels 2014a), and a meta-theoretical energy transitions framework (Cherp et al. 2018). A brief introduction to each is given in the following.

Typology of substantive transition policy options

In Chapter 2, the intended analysis required an assessment framework for comparing different transition policy strategies and instruments, both related to climate policy in particular, but also to structural change more generally. The typology of substantive transition policy options introduced by Spencer et al. (2018), developed together with Green and Gambhir (2019), fulfils all required criteria. Their approach allows for developing both theoretical and empirical insights of benefits and downsides of transition policies. With it, the distributional, economic, and political effect of transition policies can be studied. It groups transition policies into four categories, namely, (1) none; (2) backward-looking; (3) forward looking; and (4) holistic adaptive support. It captures policies aimed at specific actors as well as entire communities. Hence, transition policies are classified by their "transition policy type", and the related object (actor-type) (Spencer et al. 2018).

The second, "backward looking policy" category includes policies that aim to maintain the status quo. It aims to create a similar position for affected actors that they would have been in if no structural change forces were at play. The third, "forward-looking" category includes policies that intend to facilitate the adaptation of actors and communities to the newly existing and arising economic and policy circumstances. The fourth, "holistic support" category includes both backward- and forward-looking components, while it aims to support the adaptation of actors and communities covering a wider range and deeper change of well-being-related functionings and capabilities, as well as social, cultural and environmental values (Spencer et al. 2018). The typology is helpful for analysing transition policy strategies as it allows for including a range of instruments targeting different actor and policy types as well as to create an overview of approaches, their goals, ambitions, and actual impacts. It helps to classify transition policies, thereby providing an analytical basis for explanatory, evaluative, and prescriptive work.

Triple Embeddedness Framework

Chapter 3 applies the Triple Embeddedness Framework (TEF) developed by Geels (2014a). The TEF is part of the socio-technical transitions literature. It refers to an industry regime and firms that operate within it. The regime is conceptualised as being embedded in two external environments – the economic and the socio-political environment. An industry regime is influenced by its environments but, in turn, can also change them. The (techno-)economic environment is where economic competitiveness, efficiency, and financial performance of a firm are relevant. The socio-political environment represents the part where firms need to prove their legitimacy and social fitness to be successful. Firms respond to their environments by influencing them through strategic actions (externally-oriented responses). Firms also respond strategically to external pressures via internally-oriented strategies, aimed at changing their business approach to better fit the requirements of its environments. Overall, the framework accounts for power, strategic behaviour, and institutional change (Geels 2014a). Therefore, the TEF can be a particularly useful framework to investigate transitions, as it allows for focusing on powerful incumbents reacting to increasing pressures from the techno-economic and socio-political context. It also allows for capturing co-evolution and the bi-directional relationships between an industry regime and its environments. As Chapter 3 analyses which factors stabilise and weaken the coal regime as well as how the regime responds to such pressures, the TEF proves a useful framework to guide the analysis.

Meta-theoretical energy transition framework

Chapter 4 applies yet another transitions framework for answering the research question of what mechanisms lead to a natural gas lock-in. A framework was needed that, instead of focusing mostly on the regime, enables the analysis of the regime as one of many factors influencing the transition. Additionally, the framework needed to be open to the inclusion of the analysis of actors' perceptions of material realities and to distinguish between different lock-in mechanisms. These qualities are found in the meta-theoretical energy transition framework of Cherp et al. (2018), which focuses on three different perspectives on energy transitions. Instead of the TEF's two environments, it focuses on three systems: the techno-economic, socio-technical, and political system. The general idea is to combine insights about economic development (energy flows and markets), technological innovation (energy technologies), and policy change (energy-related policies), as each single theory by itself cannot explain transitions due to their complexity. Thus, an energy transition is conceptualised as a co-evolutionary process of all three systems. Mechanisms are identified that can explain the evolution of each subsystem, and the co-evolution of these subsystems.

The central focus of the political perspective allows for studying changes in policies affecting energy systems. Policy change is seen as a cumulative non-linear process, influenced by state goals related to national interests, the need to balance competing interests of domestic actors, and, in particular, interests by the dominant regime, which causes regime resistance. Importantly, the framework also allows for capturing international influence.

In contrast to the TEF, this framework details more explicitly which variables are part of which system. While the TEF is a useful tool for identifying single factors that influence the developments of a regime, the meta-theoretical framework allows for identifying specific mechanisms leading to inertia and changes in energy transitions more broadly. Although both are proven to be useful for the respective analyses, the second framework facilitates a more structured analysis and provides someone investigating a new field with much clearer guidelines of which factors to look out for and a more structured outcome of findings.

1.5.2 Main methods

A 'method' can be described as the procedures used for data collection or in conducting research (Goodman and Marshall 2018). Qualitative research aims to capture a specific context and the mechanisms that operate within it. Research questions, concepts, and methods in qualitative research must be reviewed and adapted repeatedly (Przyborski and Wohlrab-Sahr 2014). This section elaborates on the main methods used, namely case study research, systematic literature mapping, material analysis, historical and comparative political economy analysis, semi-structured interviews, qualitative content analysis, and background interviews (Table 1-1).

Three of the Chapters (2, 3, and 4) involve case study research. Cases are not simply used as illustrative-demonstrative case studies, but as sources for insight and analysis (Thomas 2011). A case is not “natural”, but an analytical construct to organise knowledge about reality in a manageable way and it can be used, for instance, to debunk general understandings (Lund 2014). Concepts are used to abstract from and to edit used data, as even a description needs editorial principles. Thereby, social scientists can discover connections and relations that are not directly observable (Lund 2014). The case study on the German hard coal mining phase-out between the 1950s and 2018 (Chapter 2) is of particular interest when studying the governance of fossil fuel phase-outs: Despite Germany’s historically high dependence on hard coal production for the economy, employment, and energy provision, it managed the transition away from coal. Thus, the phase-out is a valuable case to analyse the successes and failures of political measures to ease the transition as lessons for future phase-outs. The case of Polish coal in Chapter 3 is very different to the German case, as Poland is the largest coal producer in the EU (IEA 2019a) and has only in 2020 committed itself to end coal mining by 2049. This is not just a time lag between the transition compared to other EU countries, but an active choice of Poland to protect its coal industry. Therefore, it is a valuable case for analysing which factors led to the protection and lock-in of coal. The last case study in Chapter 4 looks at Germany, but this time its natural gas sector. It is an ideal case to examine the growing tension in advancing energy transitions between the expansion of natural gas infrastructure and climate protection goals: Germany is widely recognised for pursuing an ambitious energy transition while simultaneously offering strong state support for three new LNG terminals. The case is apt for studying the mechanisms leading to a strengthened natural gas lock-in. The reasons why each case study was chosen are explained in more depth in each chapter.

Chapter 5 answers a different type of question, namely what evidence exists in the sustainability transitions literature on the potential risks and adverse effects of using natural gas. To answer it, systematic literature mapping is used: Systematic literature mappings are part of the general systematic evidence synthesis methodology used to collate, describe, and catalogue existing research evidence (Haddaway et al. 2018). This method helps to describe the state of knowledge for a broader question or topic (James, Randall, and Haddaway 2016), maximising objectivity and comprehensiveness through a transparent and repeatable research processes. Not only can a systematic literature map identify both knowledge clusters and gaps, it is also particularly appropriate for describing the existing literature across a broad subject of interest (James, Randall, and Haddaway 2016; Berger-Tal et al. 2019). Literature is searched for in several literature databases, with the identified records then narrowed through a screening process based on eligibility criteria. Subsequently, the included articles are coded to extract relevant information for the respective research question. A detailed explanation of the process is found in Chapter 5.

Material analysis (used in Chapters 2,3 and 4) is similar to document analysis, and allows for including data besides original texts, such as information from interviews or workshops (which is however also the case in some understandings of document analysis (Karppinen and Moe 2012)). Not only can documents provide background and context information, historical insight, and hint at further questions that need to be asked as part of the research, documents are also a means to track changes and developments as well as to verify or falsify findings (Bowen 2009). The identification of documents and other data sources, as well as how they were used is explicitly discussed in each Chapter.

Chapter 2 examines two case studies of coal regions with a historical comparative approach. Historical because it analyses a long period in the past (1950-2018) and comparative because two different coal regions are studied, each with their own set of policies and developments, but also a comparable institutional setting. Thus, the explorative comparative study helps to identify which factors contribute to the effect of transition policies in a specific way. To do so, economic, social, and geographical indicators along with properties of both regions are used to evaluate successes and failures of implemented measures. Detailed description of the cases, data sources, and indicators are found in Chapter 2.

Another method warranting some further explanation is semi-structured interviews (used in Chapter 4). Semi-structured interviews seek to understand rather than explain something. Typically, open questions are used, with results evaluated in an interpretative rather than a statistical way (Pickel and Pickel 2009). An interview guideline is used to ensure interviews address predetermined questions (Gläser and Laudel 2010). For some information, like the interests and beliefs of actors, no written accounts exist, meaning that interviews are the best method to gain insights of key actors (Mosley 2013). Interviewee sampling should not be random but rely on structured sampling approaches. In Chapter 4, we based our sampling on an actor analysis approach (based on Brugha and Varvasovsky 2000; Reed et al. 2009), which is explained in detail in the Chapter itself. As we investigate a controversial topic, ensuring anonymity of interviewees is also crucial (Mosley 2013). As all interviews were conducted with two interviewers, we were able to take extensive notes during the interviews and to discuss the interviews immediately thereafter. All interviews were transcribed and then analysed using qualitative content analysis.

Qualitative content analysis can be performed in different ways (Mayring and Fenzl 2014). We use the approach proposed by Gläser and Laudel (2010). Importantly for a social science analysis, this method allows for following the principles of openness, theory-guided procedures, and rule-guided procedure. It extracts content from the analysed text (the interview transcripts) and allows its analysis separate from the original documents. The reconstructive investigation uses case-based explanatory strategies and reconstructs social circumstances. The interviewees selected have expert knowledge due to their participation in specific situations. The categories through which information is extracted on a nominal scale are based on theoretical considerations, but nevertheless can be changed during the extraction process. Thereby, information can be included that otherwise would not have been possible to fit in a pre-existing system. Hence, this form of qualitative content analysis is particularly useful for mechanism-oriented explanatory strategies (Gläser and Laudel 2010).

Besides the semi-structured interviews, several informal background talks without interview guidelines were held for Chapter 2, 3, and 4. These are more open, as they do not follow a clear guideline, and aim to capture factors not yet known to the researcher. As these are less formal and not recorded, a different flow of conversation arises. These background talks proved to be very useful for understanding the respective context in more depth, as it enables being introduced to many different perspectives of stakeholders and other academic experts. It is a useful method to get a first deep dive into a topic and also to check whether relevant information was missed. Academic conferences also proved very useful to get feedback on early stages of projects and to get redirected to other experts in the field.

1.6 Outline, findings and contributions of this dissertation

The overall research aim of this dissertation is to analyse historic and ongoing energy transitions, focusing on the feasibility of coal and natural gas phase-outs to achieve climate change mitigation targets. The four resulting chapters, including their topics and contribution to the literature, are summarised in Table 1-2. Their joint contributions are illustrated in Figure 1-2. As noted before, energy transitions research looks more holistically at the technical, economic, social, and political dimensions. By always including political economy aspects, this dissertation improves the understanding of coal and natural gas regimes' influence on sustainability transitions, as well as drivers and barriers for change.

The dissertation starts in Chapter 2 by looking at a historical transition process in a more established research field: The chapter aims to understand the hard coal mining phase-out from the 1950s to 2018 in Germany, specifically the governance process and structural policy measures, to derive lessons-learned for future (coal) phase-out processes. Explicitly, we find that public subsidies prolonged hard coal mining in Germany, that insufficient measures were taken to create opportunities for sustainable industries and for future generations, while the implemented policies managed to protect affected workers. Recommendations for future just transitions include more forward-looking and holistic policy approaches that take long-term impacts into account, aim at economic and structural diversification, as well as enhancing the participation of local stakeholders.

Moving on to the present, Chapter 3 analyses why similar developments have not been possible in Poland. The paper investigates the socio-political and techno-economic environments of coal production and consumption in Poland, identifying barriers for change but also drivers supporting a reduction of coal use. Interestingly, socio-political aspects mostly benefit the continued use of coal, while most economic considerations are an argument for a phase-out of coal. Derived policy recommendations combine supply and demand side policies, focusing also on regional specifics: The policy mix unites energy and climate policies targeting the decline of coal directly with renewable phase-in policies and structural policies addressing negative social impacts, while highlighting the potential of external pressures from the European Union. Lessons-learned are especially relevant for other coordinated market economies with state owned coal assets where the protection of employment is more important than the industry's competitiveness.

Chapter 4 moves from coal to natural gas, investigating the planned LNG terminals in Germany. As Germany is generally perceived as a leading country when it comes to climate change, understanding its natural gas lock-in and highlighting resulting risks is particularly instructive. The article provides valuable lessons not only for Germany but also other countries entering more advanced transition stages, as the role of natural gas in more advanced transitions is heavily contested. It highlights a particularly crucial stage of the energy transition relevant for many countries where a coal phase-out is implemented but the (political) question remains whether natural gas will instead be phased-in. For Germany, more specifically, it finds that lock-in mechanisms causing support for LNG in Germany are (A) geopolitical influence from the US; (B) security of supply concerns; (C) pressure from a wide variety of actors; and (D) sunk investments. Additional support is caused by (E) a complementary emerging synthetic gas niche; and (F) weak opposition.

Chapter 5, the last chapter, investigates the barriers of natural gas for sustainability transitions more broadly. A systematic literature mapping collates evidence on the emerging research field. It identifies the risks and governance challenges natural gas poses for ambitious sustainability transitions. The map shows that the potential of natural gas use to reduce GHG emissions is small and, therefore, that it cannot be used to achieve long-term climate targets. The risks related to natural gas are highlighted: Climate risks arise particularly due to methane emissions, techno-economic risks include crowding out low-carbon technologies, stranded assets, and infrastructure lock-in, while social risks are related to health problems and behavioural lock-in. The resulting political challenges include reaching climate targets, managing opposition, missing data and standards, as well as institutional and discursive lock-ins. The article thereby opens up a new strand of research shifting the debate from incremental GHG emission reductions and whether to reduce natural gas use to how to manage the challenges of a transition away from natural gas.

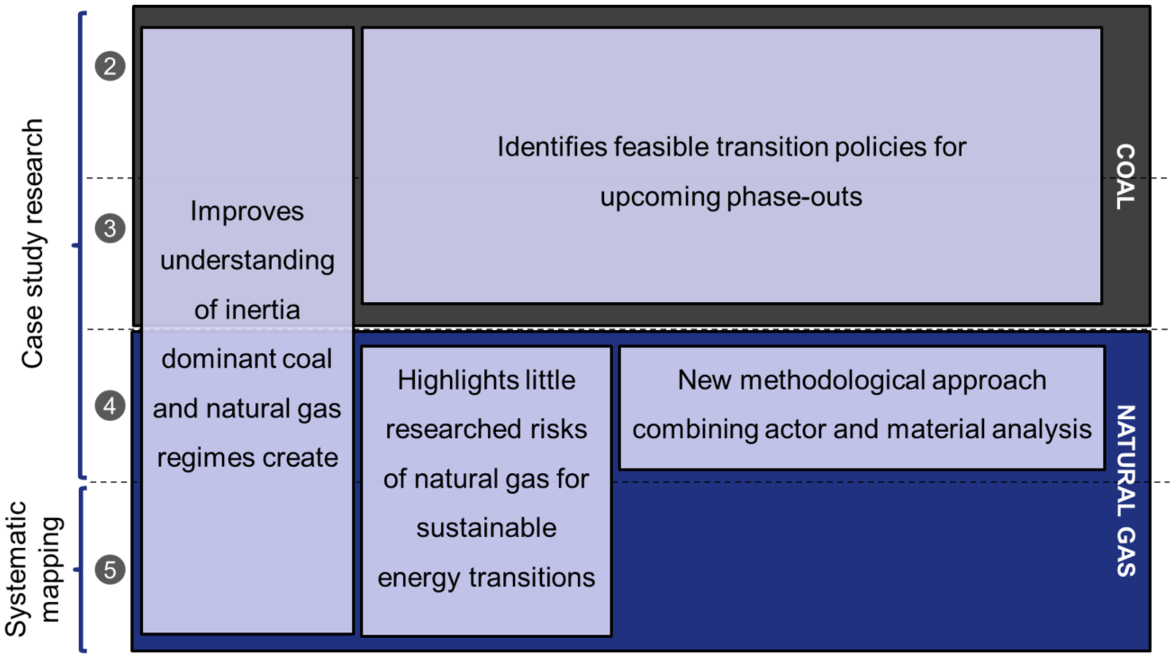

Figure 1-2: Main overarching contributions.

By applying three distinct (meta-)theoretical transition frameworks to three case studies and developing a new methodological approach on how to combine actor and material analyses, the dissertation contributes to the overall understanding of transitions as well as the effects of dominant coal and natural gas regimes and their governance. While Chapter 2 targets a transition of the past, Chapters 3 and 4 analyse the respective status quo of economic, technical, political, and social factors affecting coal and natural gas in the present. Regardless, all chapters provide lessons-learned for future transition processes. Although they target different geographical locations – Germany, Poland, and the global context – and the two different energy carriers of coal and natural gas, the main overarching finding remains the same: The respective regimes have slowed down change – and continue to do so – toward a sustainable energy system. The coal and natural gas regimes have different characteristics, such as their impacts on (regionally concentrated) employment, the involved actors and institutions, the different necessities in terms of handling (e.g., because coal is used in a solid and natural gas in a gaseous or liquid form) and resulting differences throughout their value chains. Nevertheless, the two fuels are remarkably similar in terms of the path dependencies, lock-ins, and resistance to change they create. Notwithstanding, overcoming these obstacles to sustainability transitions is technically, economically, and politically feasible, as demonstrated both by the historic hard coal mining phase-out in Germany and by on-going developments regarding a coal phase-out in Poland.

Table 1-2: Overview of topics and contribution to the literature of each chapter.

Chapter	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Transition process	Phase-out	Lock-in	'Phase-in'/ lock-in	Lock-in
Energy carrier	Hard coal	Coal	LNG/ natural gas	Natural gas
Geographic scope	Germany	Poland	Germany	Global
Research questions	Which long-term successes and shortcomings can be identified from the hard coal mining phase-out in the Ruhr and Saarland regions and what lessons do they provide for upcoming coal phase-outs?	Why does the coal regime in Poland aim at maintaining the role of coal as major energy source for the electricity industry (in contrast to most other EU states) and what role do socio-political and techno-economic dimensions play in this?	How do the material conditions around natural gas consumption and LNG infrastructure relate to and interact with actors' perceptions? How do these interactions shape systemic changes and create lock-ins for the German energy transition?	What evidence exists in the sustainability transitions literature on the potential risks and adverse effects of using natural gas?
Approach	Historical comparative political economy analysis regarding structural change processes	Material analysis and triple embeddedness framework	Actor and material analysis as part of a meta-theoretical energy transitions framework	Systematic literature mapping
Contribution to the literature	Adds to the knowledge on how coal phase-outs can be successfully governed. Identifies transferable lessons on how regional resistance and structural change can be addressed in upcoming coal mining phase-outs in other countries.	Shows that socio-political considerations mostly argue in favour and economic considerations against a continued coal use. Proposes targeted governance measures for a Polish coal phase-out with lessons for other coordinated market economies with state-owned coal assets.	Shows that a natural gas lock-in could extend from Germany to other countries in an advanced stage of energy transitions. Methodological contribution in a novel approach to combine a material with an actor analysis. Theoretical contribution in connecting the lock-in concept with a meta-theoretical transitions framework.	Shows that natural gas poses a strong set of barriers to sustainability transitions, and its use is stabilised by a set of lock-ins. Additionally indicates that long-term climate targets cannot be achieved via natural gas use. Identifies a literature gap regarding the role of natural gas in energy transitions research.

Table 1-3 provides an overview of all included chapters, the journal where the papers were (pre-)published and at which conferences they were presented as well as explicitly identifying my contribution to each paper.

Table 1-3: Overview of chapters: (Pre-)publication and own contribution.

Chapter	**Chapter 2**	**Chapter 3**	**Chapter 4**	**Chapter 5**
Title	Lessons from Germany's Hard Coal Mining Phase-out: Policies and Transition from 1950 to 2018.	The Political Economy of Coal in Poland: Drivers and Barriers for a Shift Away from Fossil Fuels.	Liquefied Natural Gas Expansion Plans in Germany: The Risk of Gas Lock-in Under Energy Transitions.	Natural gas as a barrier to sustainability transitions? A systematic mapping of the risks and challenges related to the use of natural gas.
Publication	*Climate Policy* in 2019.	*Energy Policy* in 2020.	*Energy Research and Social Sciences* in 2021.	Submitted to *Environmental Research Letters* in 03/2021.
Presentations	Semi-Plenary Policy Session at the 25th European Association of Environmental and Resource Economists (EAERE) Annual Conference in June 2020.	International Conference on Fossil Fuel Supply and Climate Policy in Oxford (United Kingdom) in September 2018. In an early stage at the Young Energy & Engineers Seminar in Łódź (Poland) and the Berlin Conference on Energy and Electricity Economics in Berlin, both in October 2017.	Presented at the Network for Early career researchers in Sustainability Transitions (NEST) digital conference in May 2020 and at the Lunch Seminar by the Physical Resource Theory Division of the Department of Space, Earth and Environment (Chalmers University, Sweden) in December 2019.	Submitted to present at the 12th International Sustainability Transitions Conference, Karlsruhe (Germany) in October 2021.
Co-authors and own contribution	Joint work with Pao-Yu Oei and Philipp Herpich. Pao-Yu Oei, Hanna Brauers, and Philipp Herpich, jointly developed the research design, collected the data and wrote the manuscript.	Joint work with Pao-Yu Oei. The investigation for the paper and the writing of the manuscript were conducted jointly. Hanna Brauers had the lead role in conceptualization, methodology and formal analysis.	Joint work with Isabell Braunger and Jessica Jewell. The conceptualisation, methodology investigation, interviews, and formal analysis were conducted jointly with Isabell Braunger. The manuscript was written jointly with Isabell Braunger and Jessica Jewell. Hanna Brauers had the lead role in the coordination.	Single-author original research article.

1.7 Concluding remarks and outlook for future research

Limiting global climate change to less than 2°C, aiming at 1.5°C, implies phasing-out coal and natural gas use in most countries before 2050. This dissertation examines those factors that prevent a faster phase-out of fossil fuels. However, my research also shows that even countries that were once heavily dependent on coal for their energy supply, economic well-being and, employment, can achieve a phase-out. A transition needs to be planned, especially to overcome resistance by key actors of dominant regimes. Identifying drivers and barriers as well as lock-in mechanisms can help to better understand the processes and, based on this, facilitate the development of (political) strategies to guide and accelerate transitions. Inertia and resistance are caused not only by industry actors, but also unions, civil society, and policy actors. Path dependencies and inertia are created not just by existing institutions, but also via technological, behavioural and discursive lock-ins.

This dissertation substantiates the only emerging debate about natural gas' role in sustainability transitions, both from an overview perspective and a case study showing the explicit mechanisms of how lock-ins and policy support are created. By contrasting two very different cases regarding coal phase-outs in the EU, the dissertation allows to understand the mechanisms of lock-in more deeply, mostly related to the same concerns and goals of the relevant actor groups. Interesting are the similarities across countries, fuels, and times. Powerful actors across private, policy, and civil society have, in all cases, managed to slow change. Nevertheless, once decline begins, the ratcheting-up of climate policy and the improving economics of renewable energies foster an accelerated decline of coal and natural gas.

The successful phase-out of coal and natural gas are important for climate change mitigation. When looking at countries where energy demand is still growing, and where high levels of energy poverty, less wealth, and limited financial capacity exist, the challenges of planning and governing successful sustainability transitions are even higher. Further research is needed to identify those additional barriers and those factors can be used to achieve a sustainability transition in these contexts.

As transitions need to accelerate to comply with emission reduction targets, critical research questions remain. In particular, it is unclear, which (novel) governance instruments and measures may be most effective and politically feasible within specific phase-out contexts. More specifically, how existing infrastructural, institutional, behavioural, and discursive lock-ins can be overcome, as well as what steps can be taken by policy, private sector, and societal actors to do so is not yet sufficiently understood. While a rich body of literature exists on the challenges regarding the mining and electricity sectors due to coal phase-outs, the heating sector may be subject to structurally different and even larger socio-technical, techno-economic, and political challenges. Thus, studying which types of lock-ins exist with regards to fossil fuel phase-outs in the heating sector would be scientifically interesting and politically valuable. The consequences of lock-ins on heating transitions and how alternatives to natural gas and coal can become feasible options for different actors are an equally relevant subject of research. Transferring lessons from the existing evidence on coal phase-outs to natural gas could advance the academic debate and, thus, ultimately improve political decision-making processes.

Chapter 2

Lessons from Germany’s hard coal mining phase-out: policies and transition from 1950 to 2018*

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*This is an Accepted Manuscript of an article published by Taylor & Francis in *Climate Policy* on November 2019, available online: http://www.tandfonline.com/ doi.org/10.1080/14693062.2019.1688636.

2 Lessons from Germany's hard coal mining phase-out: policies and transition from 1950 to 2018

Abstract

German hard coal production ended in 2018, following the termination of subsidies. This paper looks at 60 years of continuous decline of an industry that employed more than 600,000 people, through a case study comparing Germany's two largest hard coal mining areas (Ruhr area and Saarland). Although predominantly economic drivers underlay the transitions, both provide valuable lessons for upcoming coal phase-outs induced by stricter climate policies, including beyond Germany.

The analysis identifies the main qualitative and quantitative characteristics of the two regions. It then discusses policy instruments implemented to guide the transition, including measures for the conservation of coal production, regional economic reorientation, and the easing of the transition's social impacts. The success of these policies is evaluated using economic, social, and geographical indicators that were developed within three interdisciplinary research projects running from 2016 to 2019.

A key lesson from the examined case studies is the importance of combining not only policies addressing unemployment and the attraction of new energy corporations and investments, but also measures improving infrastructure, education, research facilities and soft location factors. Protecting a declining industry for decades caused increased transition costs compared to an earlier phase-out. Economic reorientation and changing regional identities have proven most difficult in the past. However, the German example illustrates that the complexity of the challenges of a transition can be mastered if city, regional, and national governments and institutions cooperate in a polycentric approach.

Highlights:

- A faster and more pro-active hard coal mining phase-out in Germany would have been much less expensive and paved the way for the establishment of new industries
- A *just and in-time transition* needs to:
    - be jointly managed in a polycentric approach by city, regional, national, and international governments and institutions.
    - combine climate, energy, social, and structural policies, whilst recognizing both local specifics and global connections.
    - consider long-term effects, external independent advice apart from the incumbent regime and beyond-border thinking, while aiming to diversify the economy and enabling broad stakeholder participation.
    - address unemployment, the economy, and the energy system, as well as measures to improve infrastructure, universities, research facilities, and soft location factors.

Keywords: Coal phase-out, Germany, just transition, structural policy, transformation

2.1 Introduction

Through the 2015 Paris Agreement, the world community committed to keeping global temperature rise “well below" 2°C compared to preindustrial levels (UNFCCC 2015). In response, in 2017, at the Bonn Climate Conference, the “Powering Past Coal Alliance” (PPCA) was founded, pledging to end unabated coal consumption in OECD countries by 2030 at the latest (PPCA 2017). By mid-2019, 32 countries and 59 sub-national governments or businesses had joined the alliance (PPCA 2019). In 2019, a stakeholder commission on ‘growth, structural change and employment’ (in the following called ‘Coal Commission’) installed by the German government recommended a coal phase-out by 2035-2038 (BMWi 2019c). Germany joined the PPCA at the UN Climate Action Summit held in New York in September 2019, when its membership structure was changed to allow countries that have set a later phase-out date to join (BMU 2019), Germany, however, remains ineligible to join the inner PPCA Declaration Group, which is restricted to OECD members with a coal phase-out date of 2030 at the latest (and non-OECD members by 2050).

Despite previously being seen as an ambitious country in climate protection, mainly because of its 2000 “Renewable Energy Act” (German: “EEG”), Germany has played an ambiguous role in international efforts to combat climate change due to its active coal mines and large coal-fired power plant fleet (Hirschhausen et al. 2018). Final legislation on a coal phase-out is still pending, while a transition in line with international climate commitments would call for an earlier phase-out by 2030 (Yanguas Parra et al. 2018; Göke, Kittel, Kemfert, Oei, et al. 2018). As the ongoing debate around and within the Coal Commission shows, key challenges include possible disruptive effects of a phase-out for the energy system as well as the social consequences for coal industry workers and related regions. Thus, the inclusion of regional aspects of social and structural policy into the phase-out of fossil fuels is a necessity for addressing (mostly local) resistance (Leipprand and Flachsland 2018; Brauers et al. 2018; Sartor 2018).

This resistance originates mostly from the injustice felt by people from the affected regions, especially by workers who fear disadvantages and losses from the shift away from fossil fuels (OECD 2019). Incorporating both structural policy and climate aspects is an important aspect of the so called “just transition” concept, specifically targeting the prospects of workers and their families (Rosemberg 2010). The concept originates from the trade union movement, which highlighted in a statement at the 2007 Bali Climate Conference that, *“(t)he effects on the economy – including on employment – will be catastrophic if ambitious measures are not taken to reduce GHG [greenhouse gas] emissions. While employment protection has often been used by certain developed country governments as a reason for not engaging in GHG emissions reductions, emerging evidence indicates that climate change mitigation has positive net employment effects”* (ITUC 2007, 4). The importance of the concept to facilitate consensus-building over the transition away from fossil fuels was highlighted further by the “Solidarity and Just Transition Silesia Declaration” issued at the 2018 Katowice Climate Conference (UNFCCC 2018).

However, the far-reaching consequences of the consumption of fossil fuels call for a wider conception of justice beyond the concerns of (mining) workers at the regional level. While the International Labour

Organisation's concept of a "just transition" focuses on securing jobs and alleviating local social problems, other concepts, e.g. environmental justice, energy justice, climate justice, and intergenerational justice, take a more global and holistic perspective, also including non-humans as subjects of justice. Under such a perspective, a faster end to fossil fuel use becomes paramount. All these concepts have in common the promotion of a transition from an extractive fossil fuel based economy to a less consuming, renewable fueled society.[3]

Bringing these different concepts together, Heffron and McCauley (2018) propose subsuming energy, environmental, and climate justice under a redefinition of the original term "just transition". We follow this approach and, because we want to stress not just the need for a socially well-managed transition, but also the urgency of a speedy transition in line with climate protection commitments, we refer to the term "*just and in-time transition*" used by the German Advisory Council on Global Change (in German, WBGU) (2018).

A well-designed energy transition can have positive side-effects on other UN sustainable development goals (United Nations 2016), including social aspects (Fuso Nerini et al. 2018; McCollum et al. 2018). Within the existing literature, however, until now, climate or structural policy aspects have mostly been analyzed separately. The literature on climate policies thus differentiates between supply-side policies targeting the extraction of fossil fuels (van Asselt and Lazarus 2018; Green and Denniss 2018) and demand-side policies that provide indirect incentives to reduce fossil fuel consumption (e.g. Fais et al (2015) on Germany). Most of these papers focus on experiences and literature directly linked to climate policies. This neglects findings from additional case studies of past economically-induced structural processes.

Initially, most academic studies on the fossil fuel phase-out process focused on the affected workers, with the environmental aspects of coal only taken into account subsequently. The literature on the German coal phase-out therefore deals with the decline of coal use (Nonn 2009; Lerch 2007), the roles of the relevant stakeholders in this process (Weber and Cabras 2017; Renn and Marshall 2016), and the impact of the changed situation in the mining regions on their spatial and economic development (Giersch 2007; Schulz and Dörrenbächer 2007). Some studies link the historical development of the coal regions with the current situation, deriving political recommendations for action (Goch 2017; Arndt et al. 2015; Bogumil et al. 2012). Other scholars investigate past coal transitions in other countries (Caldecott, Sartor, and Spencer 2017). Within this literature, the justice concept is limited to the effects in the coal regions, with little to no connection to climate justice, or the effects of climate change on other regions. With this case study, we combine these strands of literature, simultaneously looking at climate and structural policy regulation in Germany, as well as the resulting effects for the regional economies. Additionally, the paper highlights the justice implications of the German coal transition, which need to play a role in planning processes of upcoming energy transitions.

[3] In the following, the term transition refers to this understanding of switching from a fossil fuel-based energy system to a renewable one, with related changes on the technical, governance and social levels (Child and Breyer 2017).

Throughout the 20th century, most political measures to ease the transition in Germany were aimed at solving (local) economic, social and, to a lesser extent, environmental problems in the mining regions. Switching electricity production for climate reasons did not play a significant role. Consequently, when hard coal mining in Germany became too costly, it did not lead to a reduction in coal consumption, rather most coal-fired power plants switched from domestic to cheaper imported hard coal (mostly from Colombia, Russia, the USA, and South Africa). Additional environmental regulation concentrated on improving water and air quality as well as recultivation of past mining sites, but did not seek to reduce the use of coal power plants. Germany implemented additional climate political instruments, such as the Renewable Energy Act, one of the essential drivers for the (international) success of renewables (Egerer, Oei, and Lorenz 2018). The uptake of renewables at the beginning of the 21st century, however, mostly replaced the shrinking share of nuclear energy, while coal consumption stayed relatively constant until 2018 (Oei 2018).

The (predominantly) economically induced German hard coal phase-out since the 1950s is, therefore, a valuable case study for examining the reduction of coal supply (mining) while excluding coal demand (power plants). Long-term successes and shortcomings can be identified, thus providing valuable lessons for energy transition research. The analysis provides lessons not just for other countries, including Colombia and South Africa, where coal mines are likely to close in the future (Spencer et al. 2018; Sartor 2018; Oei and Mendelevitch 2019), but also Germany, where the remaining lignite mines will be phased-out within the next 20 years (Stognief et al. 2019).

2.1.1 Research aim and methodology

Germany delegates a significant number of political competencies to each constituent federal state. This provides the opportunity to examine different case studies of coal regions, each with their own set of policies and developments over a similar time period, given comparable institutional settings. In our explorative study, we analyze and compare two hard coal regions, namely Ruhr and Saarland, each located in a different federal state, thus facilitating the detection of factors contributing to the effect of transition policies (section 2.2). The data stem from available statistical information about the regional economy and industry, a review of the extensive academic and grey literature on the German coal industry,[4] and observation visits to the regions including informal background discussions with (mainly local) stakeholders comprising individuals representing government, industry, civil society, and academia. The research was performed over the 2016 to 2019 period, and conducted within the context of three separate but overlapping research projects.[5]

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[4] We conducted a search in several databases (e.g.: Elsevier, Springer Link, Google scholar and books, JStor, De Gruyter, Oxford Journals, EconBiz) looking for key word combinations both in English and German (e.g: policy, Germany, Ruhr area, Saarland, North Rhine-Westphalia, structural, innovation, transformation, labor, hard coal, economy, historical, regional, social, energy, mining). Our search resulted in a collection of around 500 related documents, of which around 100 were more closely investigated.

[5] Namely: 1) "Coal Transitions": gathering lessons learned from historic coal phase-outs and future coal phase-out strategies from six major coal-using countries. 2) "Structural Change in Coal-mining Regions as a Process of an Economic and Socio-Ecological Transformation": assessment of phase-out of coal production in the Ruhr area (Germany) and the reduction of lignite in consumption in Lusatia (Germany). 3) "Coal Exit": design a socially

This paper evaluates policy measures implemented in the two largest German hard coal mining areas in the context of the phase-out of hard coal production between 1950 and 2018, to derive lessons for future phase-out pathways, motivated by climate policy concerns. Economic, social, and geographical indicators and properties of both regions are used to enable a better evaluation of the success of the implemented measures. The choice of indicators (displayed in Table 2-1), as well as their interpretations, are based on findings of four inter- and transdisciplinary workshops held in 2017 and 2018. The workshops' participants were representatives of local governments, industry, and academia involved in structural policies, or who had a climate and energy policy background. Findings were derived by combining results from the relevant literature and actual socio-economic indicators, as well as the evaluation of impacts for affected regions by the aforementioned experts. Intermediate results were verified by presentations at a hearing in front of the German Coal Commission and at seven national and international energy or climate policy conferences. Thereafter, these were finalized using direct feedback from local representatives of the affected areas. At this time, only a few systematic approaches evaluating transition policies exist (for an exception, see Green and Gambhir (2019)). Thus, the transition policies and their outcomes are evaluated according to the typology framework provided by Green and Gambhir (2019) and Spencer et al. (2018). Section 2.3 derives the most important elements to enable a *just and in-time transition* through an inductive approach from the implemented measures described in more detail in the respective historic phase-out pathways, which are found in the Appendix 6.1. Section 2.4 concludes, providing limitations as well as lessons learned, which can be used for other transition processes in Germany or other regions of the world.

2.2 Lessons from phasing-out hard coal mining in Germany

2.2.1 Hard coal mining in Germany from 1950 until 2018

Following the Second World War, hard coal was of historic significance for West Germany, forming the cornerstone of its economic, social, and political reconstruction. In 1951, coal provided the possibility to reintegrate into international affairs in the form of the European Coal and Steel Community (ECSC), the predecessor of the European Union. The number of direct jobs within the hard coal mining industry peaked at around 600,000 in 1957, with even more people employed by indirect job opportunities. Its production took place in four underground mining areas, of which the Ruhr area was the largest (up to 123 million t/year) and the Saarland the second largest (up to 16 million t/year).[6]

Due to the extensive production of hard coal and the down-stream steel industry, the Ruhr area developed into the backbone of West Germany. It comprises several large cities in close vicinity within the federal state of North-Rhine Westphalia, forming the densest populated area in Germany. The Saarland, on the other hand, is itself a federal state that reunified with Germany in 1957 (after having been part of France (1920-1935) and then independent (1947-1957)). It is comparatively sparsely populated and forms the second smallest federal state in terms of population. Hence, the history,

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acceptable framework for an upcoming coal phase-out in Germany, as a basis for future regional transition frameworks by, among other things, analyzing past transitions and continuous stakeholder feedback.

[6] Statistik der Kohlenwirtschaft e.V. 2018a. 'Steinkohle'. Statistik der Kohlenwirtschaft. 2018. http://www.kohlenstatistik.de/18-0-Steinkohle.html.

identity, economic and social characteristics, and even legal representation at the political level vary between the analyzed regions, affecting their coal phase-out pathways (see Table 2-1).

Table 2-1: Characteristics of the Ruhr area and Saarland.

		Ruhr area	Saarland
Main characteristics of the region			
Size		4,400 km^2	2,600 km^2
Location		Close to the border with the Netherlands	At the border with Luxembourg and France
Population	1961	5,674,223	1,083,012
	Min	5,045,784 (2013)	989,035 (2014)
	Max	5,756,623 (1965)	1,132,127 (1966)
	2017	5,113,487	994,187
Population density (2017)		1,150/km^2	380/km^2
Integration to Federal Republic Germany		From the beginning in 1949	1957
Political/Spatial level		Loose regional conglomerate of cities	Federal state
Regional competition		Several, similarly large cities within close vicinity compete with each other and create (inefficient) redundant structures	Concentration on few cities
Political/administrative representation		Organized as a regional entity within NRW with only limited responsibilities	Own federal government
Overall economy within the region			
GDP (per capita) in million € (real)	1991	102,340 (*p.c.*: 44,444)	21,269 (*p.c.*: 40,055)
	2016	160,150 (*p.c.*: 66,924)	34,602 (*p.c.*: 59,346)
Homogeneity of GDP in region		In the 1990s strong differences, recently weaker cities were able to catch up	Higher GDP/capita in the cities compared to rural area
Gross value added in mill. € 2018 (share of total regional GDP)[9]	Agriculture, Forestation, Fishing	2,846 (0.4%)	62 (0.2%)
	Production industry	178,365 (25.3%)	11,066 (30.8%)
	Services	454,554 (64.5%)	21,298 (59.2%)
Mining specifications including employment			
Main energy carrier		Hard coal	Hard coal
Type of mining		Deep mines	Deep mines
Number of mines in 1957		138	17
Employees	1957	~600,000	~65,000
	1967	~290,000	~32,500
	1977	~190,000	~22,000
	2017	~4,500	~139
Ownership		Private	Public
End of operation		2018	2012

Source: Own illustration based on (Destatis 2019; Regionalverband Ruhr 2019; Statistisches Amt Saarland 2019; Statistik der Kohlenwirtschaft e.V. 2018; VGRdL 2018; Bogumil et al. 2012).

From 1958 onwards, hard coal production and employment started declining quickly due to a price drop that resulted from the liberalization of coal prices previously regulated by the ECSC (see Figure 2-1). Domestic coal had to compete with the comparatively cheaper coal from overseas and imported oil, which increasingly substituted hard coal in the heating sector. At the beginning of this coal crisis, economic circumstances in Germany allowed a majority of the former miners to transfer to the metal industries in the regions (Nonn 2001). For the remaining workers, alternatives like early retirement and retraining were offered and, hence, unemployment rates were kept relatively low (see Figure 2-2). Throughout the entire phase-out process, none of the mining workers became unemployed and all the decisions were agreed upon with the miners. This was possibly due to the co-determination law[7] introduced in 1951. However, it only covered the coal and steel sectors, not the down- or upstream industries. These latter industries were affected by the coal and steel crises, resulting in unemployment rates exceeding 15% (see Figure 2-2).

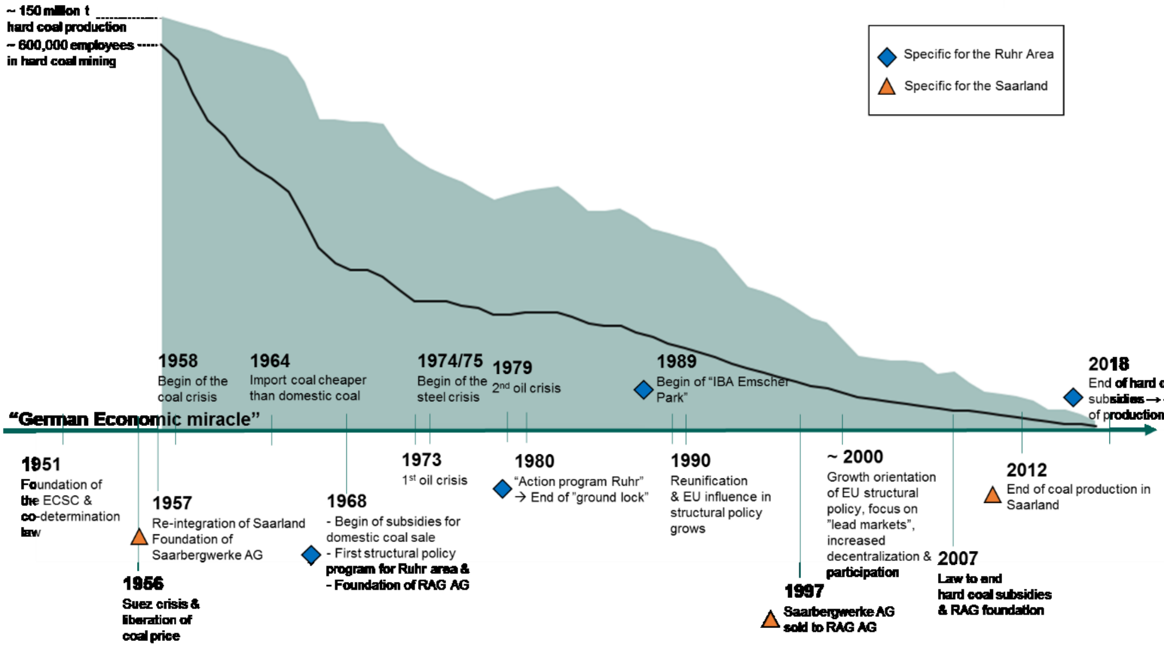

Figure 2-1: History of hard coal production in Germany and structural policy programs in the Ruhr area and Saarland from 1951-2018.

Source: Authors' illustration based on Herpich, Brauers, and Oei (2018).

Consequently, both regions tried to diversify their economies. The first structural programs sought to improve the connectivity of mining regions with neighboring cities (Bogumil et al. 2012). This meant, among other factors, investments in modern transport infrastructure to increase citizens' mobility, thus not only enabling former coal miners to travel between their homes and potential new workplaces outside the mining industry, but also increasing the attractiveness of the region for new enterprises (Goch 2009).

As depicted in Figure 2-2, the unemployment rates in both coal regions, as well as the rest of Germany, were strongly affected by the first and second oil crises in 1973 and 1979, as well as reunification in 1990. The unemployment rate of the Saarland remained below that of the Ruhr. In the 1980s and 1990s, structural policy programs focused more on ecological and cultural aspects, increasing entrepreneurial activity in the Ruhr area (Goch 2009; Hospers 2004). These efforts helped to slowly change the image of the Ruhr beyond a polluted industrial area (Rimkus 2007). The share of people working in the secondary sector decreased from 58% in 1976 to 26% in 2014, whereas the share in the tertiary sector

[7] The co-determination law from 1951 gave both employers and employees equal votes on company boards in the coal and steel sector, if the total number of employees exceeded 1,000. Both sides agreed on a neutral person to avoid stalemate by votes.

increased from 42% to 74%.[8] Like the Ruhr area, the Saarland shifted toward the tertiary sector. Increased outsourcing of services within firms previously integrated into the industrial sector strengthened this shift (Lerch and Simon 2011).

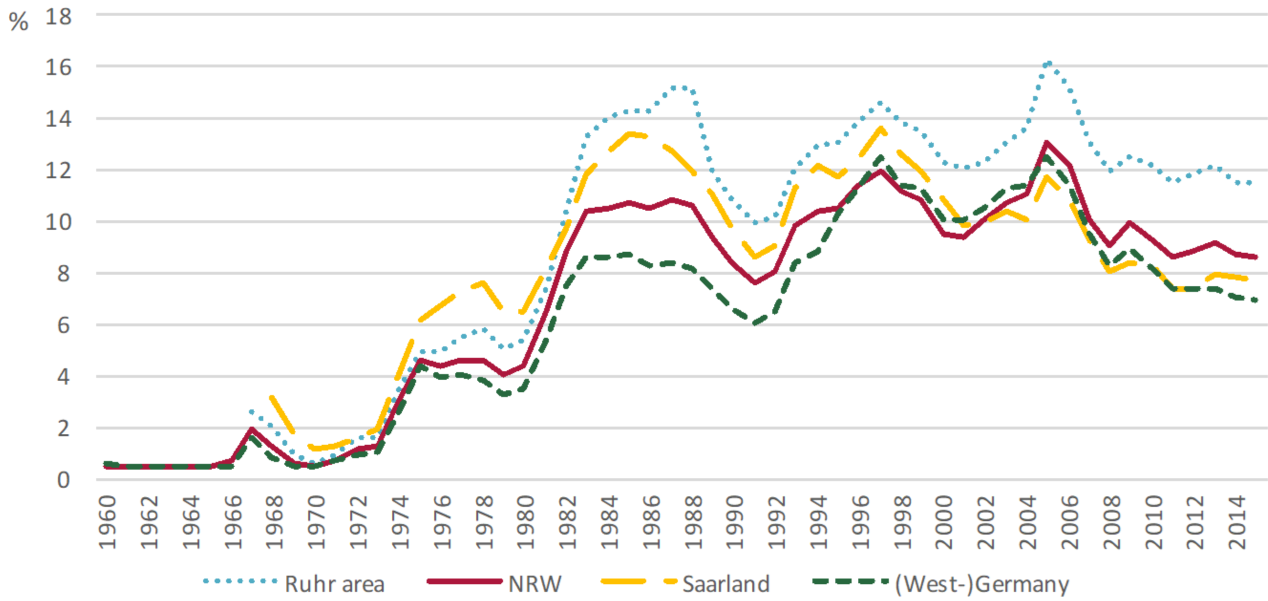

Figure 2-2: Trends in unemployment rates in the Ruhr area, North Rhine-Westphalia, Saarland and (West) Germany from 1960 to 2015.

Source: Regionalverband Ruhr (2017) and Bundesagentur für Arbeit (2018).

Note: The depicted (West-)Germany values are only for West Germany from 1960 until 1990 and from then onwards for the reunified Germany; data for the Ruhr area was available only for the years after 1966, the same accounts for Saarland after 1967.

It was only in 2007 that the growing influence of the EU forced Germany to end subsidies for hard coal production, which had reached – along with other privileges - between €289 and €331 billion between 1950 and 2008[9] (Meyer, Küchle, and Hölzinger 2010). Saarland closed its last mines in 2012, also due to growing safety concerns caused by mining related earthquakes in the region (Hartmann 2018). The last mines in the Ruhr region were closed in 2018. Research institutes, including the Leibniz-Institute for Economic Research and University Duisburg-Essen, recommended a phase-out by 2012 in order to avoid €4-10 billion in mining damages and subsidies (Frigelj 2009). Alternatively, using these funds to reeducate the remaining employees would have been equivalent to almost €1 million per worker (Frigelj 2009). The German parliament estimated the total costs for the phase-out period from 2006 to 2018 at around €38 billion, with an additional €2 billion for upcoming pensions and mining damages, and €7 billion for so-called long-term eternity costs that must be paid by future generations (Frigelj 2009;

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[8] Own calculations based on: Regionalverband Ruhr. 2017b. 'Zeitreihe Zur Erwerbstätigkeit'. http://www.metropoleruhr.de/fileadmin/user_upload/metropoleruhr.de/Bilder/Daten___Fakten/Regionalstatistik_PDF/Erwerbstaetigkeit/05_Zeitr_Ewt_SVB14.pdf.

[9] In real terms in 2008 €. Upper value includes financial support (direct and tax breaks), benefits in the emissions trade system and the costs of higher electricity prices through incomplete competition in the electricity sector.

Bundesregierung 2007). An overview of the implemented measures and instruments in the transition process beginning with the first transition policy in the Ruhr area in 1968 is shown in Figure 3. Measures that did not aim at a transition, but instead to modernize and therefore conserve the existing mining structures are marked as such.

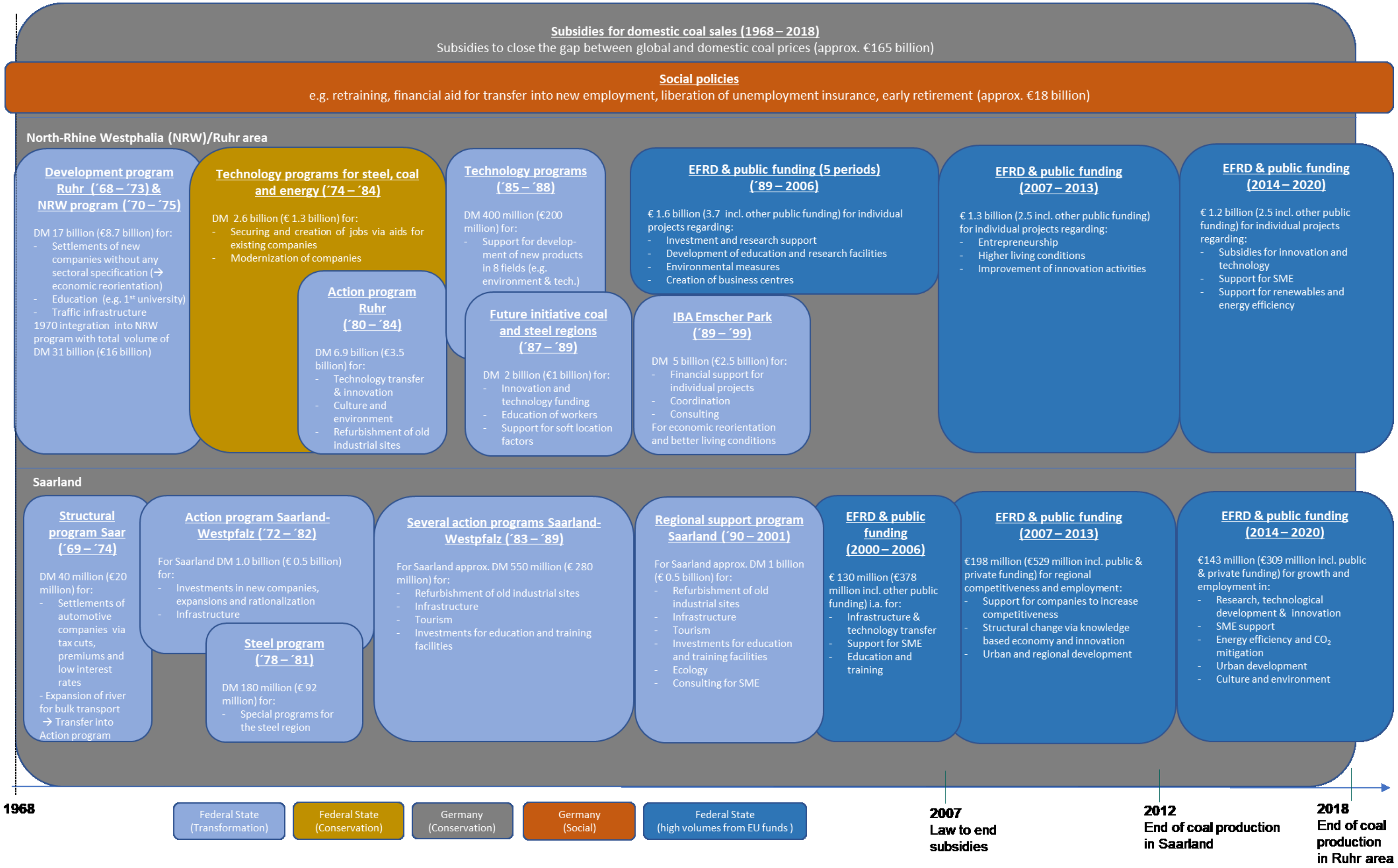

Figure 2-3: Summary of implemented measures and instruments for the Ruhr area and Saarland during transition.

Source: Authors' illustration based on (Hartmann 2018; Goch 2017; 2011; 2009; Land Saarland 2014; Untiedt et al. 2010; Meyer, Küchle, and Hölzinger 2010; Anderson 2007; Fläschner and Hunsicker 2007; Storchmann 2005; Bundesregierung 1997; 1993; 1990; 1985; 1984; 1983; Nägele 1996).

2.2.2 Experiences from the transition in the Ruhr and Saarland regions

The different underlying characteristics of the two regions (see Table 2-1) complicate a direct comparison of the two phase-out pathways experienced. The transition in the Ruhr area involved a much larger number of workers and mines than in the Saarland. In addition, public ownership granted the Saarland's government important influence over the transformation process. This section focuses on lessons that are of value for future transitions.

An important distinction between the Ruhr area and the Saarland was the differing ability to undergo an economic reorientation. In the Ruhr area, the intended economic diversification, by attracting new companies to the area, was substantially slowed by the joint resistance of mining companies, politicians, and unions (Campbell and Coenen 2017). This resistance involved institutional lock-in (network of companies, politicians, and unions), economic lock-in (high dependency on the mining and steel industry), as well as cognitive lock-in (the belief that the crisis was cyclical, not structural), leading to persistent attempts to modernize the old structures of the Ruhr area instead of turning to new economic possibilities (Goch 2009; Hospers 2004). Consequently, mining companies refused to sell the land they owned to new companies out of the fear that salaries would rise and employees would switch allegiances, working for new competitors.[10]

In the Saarland, this so-called "ground lock" was not so much of an issue, partly because of the greater influence of the state and federal government over the mining company due to its public ownership (74% federal, 26% state) and a less densely populated area. The Saarland's government implemented measures incentivizing the mining companies to offer their land and real estate to other companies. Thus, the Saarland profited from the settlement and expansion of suppliers in the automotive industry, including the Ford Motor Company, due to increasing car ownership in the 1960s and 1970s (Fläschner and Hunsicker 2007; Giersch 2007). The Saarland's favorable location, close to car manufacturers in Southern Germany, facilitated this transformation.

However, the Saarland was only able to attract companies at a large scale within a small window of time in the 1960s and 70s (Dörrenbächer, Bierbrauer, and Brücher 1988). Between 1960 and 1970, around 170 companies settled in the Saarland, creating 25,000 jobs. Along with the already present companies, approximately 40,000 coal mining jobs were replaced in this decade (Anderson 2007). Around 1970, only 4,000 former miners were still unemployed (Lerch 2007). This shows that an important goal of structural policies is not necessarily to create new industries but to attract new emerging industries and other employers to choose specific regions as places to run businesses. Furthermore, these case studies highlight that economic reorientation worked better when new projects were related to the existing industries in the cities of the mining and steel regions. Regional economic policies in the Saarland were successful because the automotive industry and its suppliers were specifically seeking a workforce with a similar skillset (Giersch 2007). On the other hand, large projects from distant,

[10] Der Spiegel. 1960. 'Flucht aus dem Revier'. Der Spiegel, 13 July 1960, 29/1960 edition. https://www.spiegel.de/spiegel/print/d-43066292.html; and Heinz, Michael. 1960. 'Ford ante portas - Kampf um die Kumpels'. Die Zeit, 29 July 1960, 31/1960 edition. https://www.zeit.de/1960/31/kampf-um-die-kumpels.

unfamiliar sectors proved less successful. For example, the settlement of Nokia in the Ruhr area in 1988 did not involve a sufficient number of local suppliers and networks, and the company left the region for Romania in 2008 following the expansion of the EU (Engel, Neumann, and Schmidt 2008; Stettes 2008).

However, this transition from coal and steel toward the automotive industry guided the Saarland into a new dependency. The newly settled companies operate globally and strategic decisions are not made in the Saarland region. Local education and research facilities have only limited possibilities for R&D cooperation and, hence, for labor market relevant developments (Lerch and Simon 2011). Furthermore, Saarland's industry relies strongly on the export of goods and, thus, depends on the global economic situation (Lerch and Simon 2011). In 2016, the automotive industry in Saarland achieved a revenue of €10 billion which equaled 38% of the industrial sector and employed more than every tenth worker (Arbeitskammer des Saarlandes 2017; Bundesagentur für Arbeit 2019). By relying on the automotive industry for job and income creation, the Saarland is again dependent on the production of a single, large industry.

At the end of the 1990s, the Saarland followed a new path, establishing research facilities connected to information technology (IT), bio- & nanotechnology, as well as medicine in order to develop an innovation-intense and growth-oriented economy (Lerch 2007). Only the IT research facilities substantially affected the labor market. The main reasons for the limited success in creating employment in other sectors was the limited independence or responsibilities of these subsidiary companies of globally operating corporations (Lerch and Simon 2011). Thus, the potential for cooperation between research and production leading to the development of new products was limited (Otto and Schanne 2006; Lerch 2007).

The transition in the Ruhr area proved to be more complicated, especially for the more northern areas. With its fully exploited coal mines, the southern areas were the first to phase-out mining, therefore profiting as first movers from direct subsidies, new ideas, and the first university. Observing fewer success stories compared to the Saarland, the structural policies in the Ruhr shifted after the 1980s toward a more inclusive approach, supporting promising "lead markets" and demanding more polycentric coordination of various governmental levels. As a result, subsidies and support schemes were spread widely across industries and sectors increasing the diversification of the region. In the 2010s, within the Ruhr area, cities became increasingly independent, empowered to create their own development strategies reflecting their individual strengths and needs. The city of Dortmund has, for example, constructed a technology center, successfully specializing in microsystem technologies, using synergies from research and innovative companies. However, such fragmentation can also result in duplicative industries and projects, preventing further growth and limiting the exploitation of the region's economic potential (Bogumil et al. 2012). This can be overcome through additional coordination, such as the joint initiative "MedEcon Ruhr" (Büter 2012): this health sector initiative, involving cooperation and coordination between cities in the Ruhr area, employs more than 300,000 people and creates more than €5 billion in yearly revenues (Büter 2012).

Table 2-2 provides an overview of transition policies between 1950 and 2018 based on the typology of Spencer et al. (2018) and Green and Gambhir (2019). The social policies, as well as the laws and contracts for the reduction of coal production with the coal corporations, were implemented at the national level and, hence, were the same for the Ruhr area and the Saarland. Additionally, the economic and structural policy programs implemented by the federal state governments in the two regions were very similar. The outcome of these policies for workers and corporations was mostly identical in both regions (apart from the point in time of mine closures/job losses). Some differences, however, prevail between the outcome for the regions, mainly influenced by the regions' specific situations (especially the total number of employees and economic dependence; compare Table 2-1). For example, although the Saarland was more successful at attracting new companies, it developed a new dependency on the automotive industry. In contrast, while the Ruhr area transformed more slowly, it managed to establish a more diversified industry structure, thus providing greater resilience to changes in a single sector.

Table 2-2: Use of transition policies in the German hard coal phase-out according to typology by Green and Gambhir (2019) and Spencer et al. (2018).

	No support	Compensation or grandfathering (backward looking)	Structural adjustment assistance (forward-looking, narrow)	Holistic adaptive support (broad)
Workers 	At the beginning of the crisis (late 1950s), lower wages without compensation	Since early 1960s: early retirement, redundancy payments Shift of employees to the steel industry Strong social security system, unemployment payments	Retraining for workers & Financial support for entering new employment since 1954	–
Regions/ Communities 	No substantial support until mid-1960s	-	Since late 1960s: Subsidies for transport infrastructure, economic reorientation and diversification, training, education and research facilities, recultivation and refurbishment of industrial sites, creation of clusters to strengthen local industries	Since the late 1980s: Integrated transition policies covering cultural and recreational and environmental aspects to improve region's attractiveness (soft-location factors)
			Regional Differences: Saarland more successful in settling new companies, esp. due to 'ground lock' by coal and steel companies in Ruhr area	Regional Differences: Saarland's regional identity less imprinted by coal 2010s: Ruhr area more diversified; Saarland dependent on automotive industry
Coal mining companies 	-	Since mid-1960s: compensation for price difference between domestic and imported coal Tax cuts, fiscal aid for financial stabilization (e.g. debt repayment, interest subsidies) State guarantee to cover 'eternity costs' if necessary	Modernization and restructuring payments: - for merging of mines and reductions in employment (1969–1987) - for mine closures (1963–1999)	-

Source: Own illustration based on (Meyer, Küchle, and Hölzinger 2010; Frigelj 2009; Bundesregierung 2007; Storchmann 2005; Bundesregierung 1997; 1983; ECSC and EC 1994).

2.3 Enabling a "just and in-time transition" for coal regions

While important lessons can be identified through the two transition pathways, there is room for improvement and neither region has yet completed a *just and in-time transition,* especially as the shift to imported hard coal neglects various elements of climate and intergenerational justice concepts. Nevertheless, the historic German experience shows that, regardless of the transition specifics, certain common dimensions must be addressed to enable a just and in-time transition within regions. Important aspects can be divided into those that are relevant mainly for the mining regions and others that must be dealt with on national or international levels. In the following, important transferable experiences with structural policies, focusing on the "just transition" elements as well as the effects on workers and the regions, are highlighted.

2.3.1 Reorientation by dissolving the coal and steel dominated local structures

A crucial step to enable a transition in the first place, is the urban and transportation transformation of the region to improve its connectedness with other (metropolitan) areas. The case of the Ruhr area, in particular, showed that existing urban structures were mostly concentrated around mining activities, leaving insufficient transport infrastructure for commuting to surrounding areas. The strengthening of the transport infrastructure in the Ruhr area also profited from its central European location, further encouraging the development of a strong logistics sector in the 1990s (Destatis 2019). Adequate infrastructure is also important for regions with lower population density, helping to stop out-migration. Earlier infrastructure projects predominantly focused on constructing highways and other roads for individualized traffic; due to climate change and related air pollution targets, this is shifting toward less carbon-intensive modes of transport, such as public transport, cycle paths and railway connections (Agora Verkehrswende 2017).

In addition to those factors visible in spatial and transportation planning that prevent a reorientation, regions are held back by other so-called "lock-in" mechanisms: i) The resistance and lock-in of the incumbent regime, consisting of the coal and steel companies, partly joined together with politicians and trade unions; ii) problems for domestic industries caused by increasing competition due to globalization; and iii) the misjudgment of the true nature of the coal and steel crises, which prevented action implementing deeper and earlier restructuring measures (Dörrenbächer, Bierbrauer, and Brücher 1988; Hospers 2004). The close political links within the incumbent regime, in particular, resulted in subsidies and concessions that ensured continuity despite economic inefficiency, as seen in both case studies. Support schemes and subsidies should be directed toward new, more sustainable, industries (see section 2.3.2) and toward strengthening soft location factors (see section 2.3.2).

2.3.2 Attracting (new) industries and labor policies

Both mining areas had similar structural problems following the coal crisis, both looking for alternative industries. However, the close ties between established companies and politicians prevented the creation of a whole network of up- and down-stream companies in most cases. Neither the mining companies nor the state government offered their land to new companies and prevented the establishment of the Ford Motor Company in Herten and Hamm (Ruhr area) in the 1960s for example. Opel, another car company, was only able to settle in Bochum (Ruhr area) because of additional support of the municipality (Nonn 2001). The Saarland, on the other hand, succeeded in attracting the Ford Motor Company in the 1960s through subsidies, premiums and tax concessions. This shows that the settlement of a new industry depends on the location, the timing, as well as the availability of trained workers and available space. The unsuccessful example of Nokia in the Ruhr area, however, also shows the problems of increasing competition in a globalized world. The formation of a network (of suppliers) within the area proved to be an important factor for the survival of the Saarland automotive industry through subsequent crises (Georgi and Giersch 1977). Enlarging such networks with universities and research centers to spark innovation resulted in the formation of clusters that strengthen local industries (Rehfeld and Nordhause-Janz 2017; Heinze 2006).

Besides replacing mining jobs with new jobs in other industries, active and passive labor market and social policies play a major role in a just and in-time transition. Anticipative elements, like retraining and the early communication of phase-out plans, can ease the disruption of upcoming changes, helping coal miners to stay in the labor market and encourage new generations to choose education and employment tracks with better future perspectives (Mayer 2018; Healy and Barry 2017; P. Newell and Mulvaney 2013). In the German case, early retirement was a frequently used measure for easing labor market tensions and to help miners above a certain age (Frigelj 2009). According to the hard coal financing law from 2007, every worker older than 42 was protected against unemployment. After the end of their employment in coal mines in 2018, workers would work three years in decommissioning and then receive payments for another five years to bridge the time until they entered the regular pension fund at age 62 in 2027 (Frigelj 2009).

Renewable energy is a promising new employment sector for future transitions away from fossil fuel industries, with the sector already employing around 350,000 people in Germany (Egerer, Oei, and Lorenz 2018) and around 11 million globally (IRENA 2019). Regions with coal power plants are potentially well suited as they have a high competence in energy industries, a positive connotation and historic identification with energy installations, as well as much of the needed infrastructure requirements, e.g. high-voltage electricity access or industrial complexes. It is important to ensure that lost jobs are replaced with new comparable jobs, not only in quantity but also quality (Lerch and Simon 2011).

2.3.3 Including soft location factors and regional identities

Besides infrastructure, the absence of a university within a region of at least five million people highlights the former strong focus on coal and steel production within the Ruhr area. An expansion of the educational system in the mining regions is, on the one hand, important for giving the population the opportunity to adapt to the new labor market conditions. On the other hand, it helps to mitigate the threat of out-migration due to a lack of educational opportunities in the region, while also encouraging immigration from other regions. Education and research institutions can play an important role in enabling a shift from mining toward a more knowledge-based society (Kriegesmann, Böttcher, and Lippmann 2016). Supporting higher education boosts high-value adding sectors, increasing demand for highly skilled workers and research-based innovation. In 2014, the Ruhr profited from 22 universities with more than 250,000 students (Kriegesmann, Böttcher, and Lippmann 2015). The opening of these universities enhanced the attractiveness of the region for companies and for citizens, constituting an important location factor. Integrating universities and research facilities with networks of companies and other institutions creates competitive and resilient structures that keep companies in the region and attract new ones (Stognief et al. 2019).

Soft location factors, like cultural and leisure time possibilities, as well as environmental issues (e.g. air pollution levels and clean rivers), play an important role in the public perception of a region. They increase the quality of life in the region and can convince people not just to stay, but also to move there. In the Ruhr, the total net migration from 1977 until 1986 increased to -158,000.[11] Thus, the structural policy programs "Action Program Ruhr" (1980) and the "IBA Emscher Park" (1989), put a specific emphasis on improving soft location factors. In the following years, former industrial sites were transformed into landmarks and cultural sites not just to celebrate the region's identity, but also to enable a shift toward a new, more future oriented, perception of the region (Goch 2009). Subsequently, the total net migration turned positive with a population increase of +247,000 people between 1987 and 1995.[12] Incorporating soft location factors into cohesion policies through the participation of local stakeholders from the start can help change perceptions and increase acceptance of upcoming transitions.

2.3.4 Managing the transition

A challenge for the development of structural policy was to identify the right system of governance to guide the transition, especially within Germany's federal context. The first large projects initiated at a national level were ineffective, facing both regional and local resistance. Thereafter, decision making and planning shifted to a more regional level, taking account of endogenous local potentials and enhancing public support for the transition by increasing bottom-up participation of local stakeholders (Goch 2009). This enabled each region to benefit from its individual strengths and, simultaneously, in comparison to top-down decision making, reduced local resistance against the transition. Additional coordination of these various polycentric measures is needed to enable an efficient and sufficiently fast transition process. The establishment of one institution with sufficient capacities representing the entire Ruhr area helped to coordinate national funding. Nevertheless, it is not always possible to create a coherent strategy for all cities within a region (Bogumil et al. 2012; Metropole Ruhr 2018). The multicentricity of the Ruhr area means that redundant developments of cities within close proximity slowed down the transition; a more coordinated strategy would tap its full endogenous potential. Future phase-outs in regions similar to that of the Ruhr should create organizational units that are able to develop and implement such strategies in a coordinated way, thus facilitating a more efficient and rapid transition.

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[11] Regionalverband Ruhr. 2017a. 'Bevölkerungsbewegung in der Metropole Ruhr - Zeitreihe seit 1962'. 2017. www.metropoleruhr.de/fileadmin/user_upload/metropoleruhr.de/05_MR_Sonstige/Excel/Statistik/Bevoelkerung/Zeitreihe_Bevoelkerungsbewegung.xlsx.

[12] Ibid.

For the German hard coal mining phase-out, the majority of costs were linked to structural and social policies designed to slow down the economically driven phase-out, as depicted in Figure 2-3. A just and in-time transition requires financial resources and a fair distribution of the responsibilities for the costs. In the German case, most of the subsidies for the Ruhr and Saarland were financed through the national budget. As future coal phase-outs are expected to mostly involve political decisions motivated by global climate change concerns, costs should not only be borne by the regions but rather by the whole country, if not internationally. Furthermore, it is necessary to implement measures that secure enough financial resources from coal companies to cover the costs caused by their operations (e.g. recultivation costs and compensation of relocated settlements). For an overview of potential measures, see Oei et al. (2017).

2.4 Conclusion

The Ruhr and Saarland experienced a 50-year-long, predominantly economically driven decline of their coal industries. Since 1960, many different structural and societal policy measures at the national and state levels were sought to regulate – typically to slow down – the rate of necessary structural changes. The decision that most prolonged German hard coal production was to support the mining companies with public subsidies. It also meant that none of the former workers were left behind, thus securing a claim for a just and in-time transition. On the other hand, insufficient measures were taken for the creation of new potential for upcoming generations and more sustainable industries. Further, the shift to imported hard coal for power plants ignored the global climate, social, and environmental effects of burning coal. In this respect, the hard coal mining phase-out in both regions failed to achieve a just and in-time transition. Nevertheless, this analysis provides some transferable lessons on how regional resistance and structural change can be addressed in the future.

The main lessons of the two case studies with resulting recommendations are:

Refrain from subsidizing the coal industry: Instead, the formal and informal political influence of the coal companies must be weakened in order to overcome the lock-ins, thus enabling economic reorientation. Currently, G20 states are still spending around US$39 billion on coal production each year (Climate Transparency 2019); in line with the PPCA commitments, these should be abolished.

Take into account long-term effects and impacts beyond the local communities in decision making: The aim of leaving no one behind was not fully met, as future generations within the region as well as international actors (to account for climate and environmental justice effects along the entire value chain) were not included in the transition's decision making processes.

Listen to external independent advice in addition to the incumbent coal regime: An earlier phase-out, as recommended by academics, would have been less expensive, caused less environmental devastation, and most likely resulted in a faster recovery of the regions.

Diversification can minimize the risk as no "silver bullet" exists: It is difficult to attract and predict the success of new industries. The Saarland was more successful earlier on; however, its new dependence on the automotive industry creates the next threat. In contrast, the Ruhr economy transformed slower but is now more diversified.

Participation enables locally adapted solutions and higher acceptance: The involvement of local stakeholders is important for identifying strengths and weaknesses of the regions in terms of adjusting, developing, and implementing local strategies.

Encourage cooperation through crossing borders: Appropriate structures must be created to enable a joint post-carbon strategy for entire mining regions, independent from administrative federal or national borders. Political institutions focused on social, labor, spatial, and energy planning must combine efforts, facilitating the establishment of an integrated, coherent policy mix.

The two cases examined involve relatively wealthy, old, industrial regions in a central European location, with relatively high population densities and proximity to supra-regional conurbations. This is a major advantage for the promotion of projects and the establishment of companies, which does not apply to all mining regions. The transition of both regions is not solely attributable to declining coal production; the diminishing importance of the steel industry also played a role. In addition, political and administrative structures are integral in the allocation of funding: Germany's federal structure enabled mining regions to acquire significantly more funds than comparable regions in other countries, thus the costs of transformation were easily externalized to the national level (Feld, Schnellenbach, and Baskaran 2012).

The findings from this study could be used to examine differences between comparable past coal mining phase-outs, especially within Europe, e.g. the UK or Spain. Furthermore, the findings are of great importance for the ongoing German discourse on the phase-out of its remaining coal assets. In most regions, coal transitions will include a phase-out of mining and power plants, resulting in the challenges of providing new employment possibilities as well as replacing coal power plants with renewable energy sources. A comparison is also possible with coal exporting countries like Colombia and South Africa, where the focus will lie on the effect of mine closures in affected regions. Combining climate, energy, social, and structural policies, whilst recognizing both local specifics and global connections, can help guide a just and in-time transition away from fossil fuels.

Chapter 3

The political economy of coal in Poland: Drivers and barriers for a shift away from fossil fuels*

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Published as: Brauers, Hanna, and Pao-Yu Oei. 2020. ‘The Political Economy of Coal in Poland: Drivers and Barriers for a Shift Away from Fossil Fuels’. *Energy Policy* 144 (September): 111621. https://doi.org/10.1016/j.enpol.2020.111621.

3 The political economy of coal in Poland: Drivers and barriers for a shift away from fossil fuels

Abstract

Poland is the largest hard coal and second largest lignite producer in the EU, generating around 80 percent of its electricity from coal. Resistance to a reduction in coal production and consumption comes from various actors, namely, coal corporations, unions, parts of civil society and the government – as well as their coalitions. Their opposition centres around the prospect of losing their business, past negative experiences with structural change, fears of rising energy prices and energy security concerns, as well as potential unemployment in regions almost entirely dependent on coal.

This paper identifies key political and economic drivers and barriers of a reduction in coal production and consumption in Poland using the Triple Embeddedness Framework. Uneconomic coal mining, unavoidable energy infrastructure investments, rising air pollution levels and pressure from the European Union might provide new political momentum for a shift away from coal in line with international climate targets. However, results show that to achieve political feasibility, policies targeting a reduction in coal production and use need to be implemented jointly with social and structural policy measures, addressing a just transition for the affected regions in line with the vision of a 'European Green Deal'.

Highlights:

- Coal's incumbency is stabilised by links between firms, policy makers and unions.
- Drivers for coal phase-out: uneconomic mines, old infrastructure, pressure from EU.
- Complement coal phase-out with social and structural policies for a just transition.

Keywords: Poland, coal phase-out, energy transition, Triple Embeddedness Framework, political feasibility, political economy

3.1 Introduction

Greenhouse gas emissions related to coal combustion are the biggest single contributor to global climate change. In order to avoid exceeding dangerous levels of global warming by 1.5°C or 2°C, burning coal needs to be cut drastically in the coming decades (UNEP 2017, chap. 5; Rockström et al. 2017; McGlade and Ekins 2015). Internationally, efforts to curb coal production and consumption are increasing, as demonstrated by e.g. the Powering Past Coal Alliance (see e.g. (Green 2018; Jewell et al. 2019)) and the commitment of many European Union (EU) countries to a coal phase-out. This shift away from coal can be seen as one important pillar of the sustainable energy transition.[13]

[13] 'Energy (system) transformation' and 'energy (system) transition' are frequently used interchangeably in the scientific discourse, although differentiations – such as a stronger focus on societal contributions to change in the energy transition literature, or bottom-up 'transformations' rather than top-down structured 'transitions', as well as the transformation term comprising comprehensive social upheavals - have been identified (Child and Breyer 2017).

So far, the main focus on how to reduce coal (and more generally fossil fuel) consumption and production was on demand side policies (e.g. carbon pricing or emissions performance standards for coal-fired power plants). This is increasingly complemented by more research on supply side policies (e.g. a moratorium on new mines or enforced mine closures; see Special Issue on 'Fossil Fuel Supply and Climate Policy' (van Asselt and Lazarus 2018), Mendelevitch, Hauenstein, and Holz (2019) or potential effects on coal exporting countries (Oei and Mendelevitch 2019; Richter, Mendelevitch, and Jotzo 2018)). Supply-side policies can e.g. contribute to reducing overall mitigation costs, slowing down investments in fossil fuels, limiting carbon lock-in effects, increasing moral pressure as well as public support for climate protection measures and restricting a short-term production increase (Lazarus and van Asselt 2018).

This is complemented by research focusing specifically on coal transitions, combining the analysis of supply and demand side policies as well as climate policy and transition (e.g. social and regional) policies (Spencer et al. 2018). The combination has been found to be so important as, from a political economy perspective, policies tackling the transition just from only one of these aspects has proven very challenging. Especially anticipatory and long-term policies to support affected regions need to be included in a successful climate-policy induced coal transition policy mix (Spencer et al. 2018; Sartor 2018; Oei et al. 2020).

Poland, until now, shows little ambition to limit its coal extraction and use – as can be seen within its newest National Energy and Climate Plan (NECP)[14]. It is an interesting country to study for two main reasons. Firstly, it is the largest hard coal producer and second largest lignite producer in the EU (IEA 2017a). Unlike other main coal producers in the EU (e.g. the UK, Germany, Spain, etc.), Poland has not committed itself to end coal mining. Secondly, Poland does not only lag behind in its missing commitment to end coal and to reduce its energy dependence on coal as main energy carrier, but is also one of the main countries vetoing EU policies that aim to increase climate protection ambitions (Jankowska 2017). This shows that it is not just a time lag between the transition compared to other EU countries, but an active choice to protect its coal industry. At the international climate conference COP 24 in Katowice, coal was proudly showcased, while President Andrzej Duda confirmed that *"there is no plan today to fully give up on coal"* and that Polish supplies would last for another 200 years.[15] Poland has hence become an outlier within the EU, which makes it an interesting case to analyse which factors hinder the necessary transition and which policy options might overcome this.

Explaining current policy outcomes regarding coal in Poland, but also in other countries, requires recognising the political influence of powerful stakeholders (Goulder and Parry 2008). In recent years, attention in academic literature looking at energy transitions has shifted from a more technical and

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In the following, we use the term 'transitions' to refer to substantial changes in societal, economic and, more specifically, energy systems. The term transformation will be used if scholars explicitly refer to it.

[14] gov.PL. 2019. 'Executive Summary of Poland's National Energy and Climate Plan for the Years 2021-2030 (NECP PL)'. https://ec.europa.eu/energy/sites/ener/files/documents/pl_final_necp_summary_en.pdf.

[15] Reuters. 2018. 'Katowice COP24 Notebook: Spotlight Descends on Mining'. https://af.reuters.com/article/worldNews/idAFKBN1O41NE.

innovation perspective – with a focus on renewables and niche-innovations support (Bergek et al. 2008; Geels 2002; Smith, Voß, and Grin 2010) – to the general call for a stronger integration of social sciences in energy and transition research (Sovacool et al. 2015) – including the analysis of how the incumbent fossil fuel regimes can be destabilised and eventually replaced (Kivimaa and Kern 2016; Kungl and Geels 2016; Turnheim and Geels 2013).

Resistance to a shift away from coal originates from various actors – namely, coal firms, unions, parts of civil society, and the government – albeit for different reasons. Policy outcomes regarding coal production and consumption are deeply influenced by these actors and their coalitions, as analyses for other countries have shown (Leipprand and Flachsland 2018; Kungl 2015; Turnheim and Geels 2013; 2012; Brauers, Herpich, and Oei 2018; Vögele et al. 2018).

Politics and power (structural forms, institutional politics and discursive expressions of power) are important for the creation of a certain pathway. A transformation is not planned and then put into place by politicians. It is rather a "*product of competition and interaction between a number of pathways, supported by diverse social actors with highly uneven political power*" (Scoones, Leach, and Newell 2015). Hence, looking at the various actors in and around the coal regime in Poland, their interests, relation, and their influence is important to explain why the coal regime has been able to uphold its position.

In addition to politics and power, economic development and technological innovation are important elements influencing energy transitions (Cherp et al. 2018). A framework suitable to include all these factors is the Triple Embeddedness Framework (TEF) (Geels 2014a), which conceptualises interactions of an industry regime with its economic and socio-political environments. Although the TEF focuses on the technological and market level, it enables the incorporation of state and citizen power, as well as politics in general. Regime destabilisations, as transformations in general, have never been linear, structured, and planned with specific targets, but are always messy and contested (Scoones, Leach, and Newell 2015). The TEF enables the descriptive analysis of main trends influencing the coal regime to make sense of such past developments.

We combine this socio-technical transitions approach with political economy thinking, which has been identified as a research gap in energy transitions research (Goldthau and Sovacool 2012; Meadowcroft 2011) and is increasingly becoming a focus of analysis (see e.g. Newell and Mulvaney (2013); Baker, Newell, and Phillips (2014); Power et al. (2016); Kern and Markard (2016); Arent et al. (2017); Paterson and P-Laberge (2018)). Importantly, it complements the more innovation and techno-economic focus of the socio-technical transitions literature with aspects of power, interests, institutions, discourses and politics. The political economy literature puts emphasis on the influence of power imbalances, political business cycles, (informal) actor networks, institutions and inequality.

This paper aims to contribute to the literature by analysing why the coal regime in Poland aims at maintaining the role of coal as major energy source for the electricity industry (in contrast to most other EU states), and which role socio-political and economic dimensions play in this. To answer this question, we analyse which actors (and their networks) are supporting coal and which actors and interests might have already started to destabilise the coal regime. The paper identifies drivers and barriers for a reduction of Polish coal dependence, acknowledging the underlying politics as well as the technical, economic and social context.

The analysis of the coal regime in Poland for three decades from 1990 until 2019 is followed by an analysis of how policies addressing the reduction of coal production and consumption can be complemented by structural policies to increase political feasibility. The paper proceeds as follows. Section 3.2 introduces the theoretical background and methodology. Section 3.3 presents the status-quo of coal in Poland and conducts the analysis of the political economy of coal. Section 3.4 looks at supply and demand side policy options to accelerate a decline of coal, as well as structural policies suitable for the current status of the political economy. Section 3.5 concludes. The Appendix 6.2 gives a more extensive description of the situation of coal in Poland and the TEF analysis.

3.2 Methodology

3.2.1 Theoretical Background: The Triple Embeddedness Framework

The TEF is a conceptual framework developed by Geels (2014a) that is part of the socio-technical transitions literature (for further information see Appendix 6.2.2). The framework refers to the situation of firms within an industry regime, which is itself embedded in two external environments – the economic and the socio-political environment. An industry regime is influenced by its *socio-political* environment, where e.g. legitimacy and social fitness determine its success, and the *economic environment* that demands economic competitiveness, efficiency and financial performance. The TEF acknowledges the ability of firms to respond to their environments and influence them through strategic actions. The responses of firms-in-industries are both externally-oriented (towards the economic and the socio-political environment) and internally-oriented (Geels 2014a). The TEF enables us to investigate how incumbency can be weakened when single pressures from the two environments align.

Industries that can be analysed with this framework are reluctant to change, hold a high political influence and are scale-intensive with many sunk investments, which is all true for the coal sector. The TEF recognises institutional change and includes strategic behaviour as well as power of actors. By enabling the analysis of the co-evolution and the bi-directional relationships between an industry regime and its environments, the TEF addresses shortcomings of previous methodologies (e.g. industrial economists focusing only on economic pressures or neo-institutionalism simply on socio-political pressures) (see Kungl and Geels (2018) for discussion).

The framework is part of the field of sustainability transition studies, where the most prominent theoretical frameworks encompass transition management, strategic niche management, the multi-level perspective and technological innovation systems (Markard, Raven, and Truffer 2012; Fünfschilling and Truffer 2014). For several reasons, they are not suitable for our research questions: One of the criticism of all four approaches is that they have a “rather unpolitical understanding of transitions” (Haas 2019b), however, the Polish case can only be understood when including politics. Also, the multi-level perspective (Geels 2002) and strategic niche management (Kemp, Schot, and Hoogma 1998) focus on emerging niches and changes to a system. Hence, those approaches are not useful for this analysis, as it focuses on the incumbent regime itself (see also Johnstone, Stirling, and Sovacool (2017) and Kivimaa and Kern (Kivimaa and Kern 2016) for a discussion on regime destabilisation) and aims to identify stabilising factors, besides the ones enabling change. The technological innovation systems approach (Carlsson et al. 2002) puts a specific emphasis on the interaction of actors including firms, but the approach is also most suitable for the analysis of niches and innovation processes, while we focus on the opposite – prevention of innovation and inclusion of new technologies. Transition management focuses on active government intervention, being partly prescriptive and focusing on strategic, tactical, operational and reflexive management approaches (Loorbach 2010). This framework would not enable us to understand the economic or technical context sufficiently.

Hence, we chose the TEF, as it makes it possible to focus on the incumbent regime, while it also enables us to include politics and structural power as well as historical developments (see also Johnstone and Newell (2018)), allows us to apply a political economy perspective to understand the particularities of the Polish situation (see also Newell and Paterson (1998), Levy and Newell (2002) and Newell (2018)), and nevertheless include technology developments and the country specific societal context as relevant influencing factors of sustainable energy transitions. By highlighting the embeddedness of the regime in the socio-political and techno-economic environment, we can highlight how the incumbents protect their interests and create lock-ins into coal dependence, but also identify current threats to coal's dominance and potential avenues for change.

3.2.2 Data collection and framework application

The TEF has been applied in several case studies, e.g. to analyse the destabilization of the British coal industry (Turnheim and Geels 2012; 2013), in the context of electric mobility (Sovacool, Noel, and Orsato 2017) and incumbent electricity utilities in Germany and Switzerland (Kungl and Geels 2018; Mühlemeier 2019). To our knowledge, we are the first to apply it to the case of Polish coal use.

Data-collection is guided by the conceptual framework focusing on the relevant actors and contexts rather than on dependent and independent variables (Kungl and Geels 2016; 2018). Our explorative study relies on a literature review to determine the general political, technical and economic situation of coal, it's social relevance and aforementioned actors' positions. Collection of data on this includes primary literature, such as statements provided by ministries, unions and NGOs, company press reports and annual reports, as well as a range of daily newspaper articles and blogs. The secondary literature used comprises of scientific peer-reviewed journals, as well as other articles, reports and books. Additionally, we consulted databases, e.g. by the Central Statistical Office of Poland, to obtain information on the development of coal mines, power plants and employment figures. In total we collected and analysed more than 600 documents, mostly written in English or German.

To gain a deeper understanding of the Polish situation regarding coal, we had several informal background discussions with Polish stakeholders on research visits to Warsaw, Łódź and Katowice in 2017 and 2018, involving industry, civil society, and academia representatives. A potential shortcoming is that only English and German documents[16] and no unofficial/secret government or corporate

[16] As none of the authors speak Polish, no Polish texts were analysed.

documents have been analysed. However, we believe this has at least partly been corrected for by discussions of preliminary results and draft versions of the paper with Polish energy sector experts.

The extracted information from these different sources is then analysed with the TEF framework (compare e.g. with the approach taken by Vögele et al. (2018)). The inductive approach intends to generate new insights about the Polish coal sector based on empirical data. In our iterative approach we refined intermediate results after presentations and discussions with (Polish) stakeholders at five international academic conferences.

The main aim of the paper is to provide an overall picture of the Polish political economy of coal in a novel way. Many of the single elements included in the TEF have been studied by other authors. Our main contribution is to bring these empirical results into the descriptive framework to better understand the complexities of the many mechanisms influencing the political economy of coal in Poland. We derive policy implications through the identification and comparison of main drivers and barriers of a coal phase-out.

Actor groups which are included in the analysis due to their importance for the coal industry more specifically, and sustainability transitions more generally, are the firms of the incumbent coal regime, non-governmental organisations (NGOs), governments, labour unions, civil society and competitors for coal (based on Hess (2014) and Turnheim and Geels (2013)). The analysis is conducted over the time period from 1990 to 2019, as the destabilisation of a regime is a long-term process and historic events can reveal broader societal and economic trends creating path dependencies and lock-in effects (see also Kungl and Geels (2016)). Also, most data are only available post-1989, after the end of the communist regime in Poland.[17] A special emphasis is put on the more recent past after the Paris Agreement and the election of a new Polish government as well as leading up to COP 24 in Poland from 2015-2019. Due to the close connection of upstream coal mining and coal use for downstream electricity generation, both are included in the coal regime analysis.

3.3 Results

The following section includes the analysis of the three main elements of the TEF: The socio-political environment, the economic environment, and internal as well as external response strategies by the regime to those influences.

3.3.1 Socio-political environment analysis of Polish coal industry

Poland is, as a legacy from the communist regime, very centralised (Baran et al. 2018). The national Polish government, now a coordinated market economy (Rentier, Lelieveldt, and Kramer 2019), has continuously supported the coal industry, even though it also managed the historical decline e.g. by enforcing the closure of the most inefficient mines (Szpor 2017; Zientara 2009). The coal sector's inefficiency due to overcapacity and over-employment inherited from Soviet-era influence was targeted

[17] A detailed description of the development of the Polish coal sector, including periods before 1990, can be found in the Appendix 6.2.1.

for the first time at the beginning of the 1990s. In 1990, almost 388,000 people worked in Polish coal mines (Szpor 2017). During the 1990s, four different government programs led to several mine pits closures, while other mines were grouped together (profitable with unprofitable ones) and later merged into larger coal corporations (Baran et al. 2018; Suwala 2010; Zientara 2009). Decisive restructuring failed in important factors including the total expenditure levels, delays in decisions of employment cuts and a missing legal framework (Zientara 2007; Suwala 2010). By 2015, 99,500 miners were left with around 13,000 people employed in coal fired-power plants (Alves Dias et al. 2018, 21).

A very dominant influence on the socio-political environment and hindering coal industry restructuring has been, and still is, the miners' unions. Their political power led to high employment and high salaries, even in times when the coal sector was in a very poor state (Gurgul and Lach 2011). The extent of Polish coal miners' power becomes apparent when comparing their status to miners in other countries: Polish miners work fewer hours a day and fewer days a year, have additional public holidays, additional monthly salary, benefits for long-term employment and earlier retirement options. Trade unions fought hard to obtain these working conditions. They exert political power by lobbying through direct talks with politicians but also strikes (Trappmann 2012). The government's first attempt in 1991 to restructure the unprofitable mining sector failed due to internationally low prices for coal and the strong political power of the trade unions. The unions successfully resisted all proposals to reduce wages or to cut employment until around 1996 (Suwala 2010).

A government programme from 1998 was successful in winning support from unions as well as corporations for the restructuring program and related mine closures. Efficiency of mines increased for the first time, especially by reducing employment numbers. Workers losing their jobs got retirement benefits but no retraining (Suwala 2010). Less than three percent of all expenditures on restructuring programs during these years went to job creation in other sectors. As local authorities, which were meant to create new job opportunities, had little experience with this task and received no support, success in that respect was very limited (Suwala 2010).

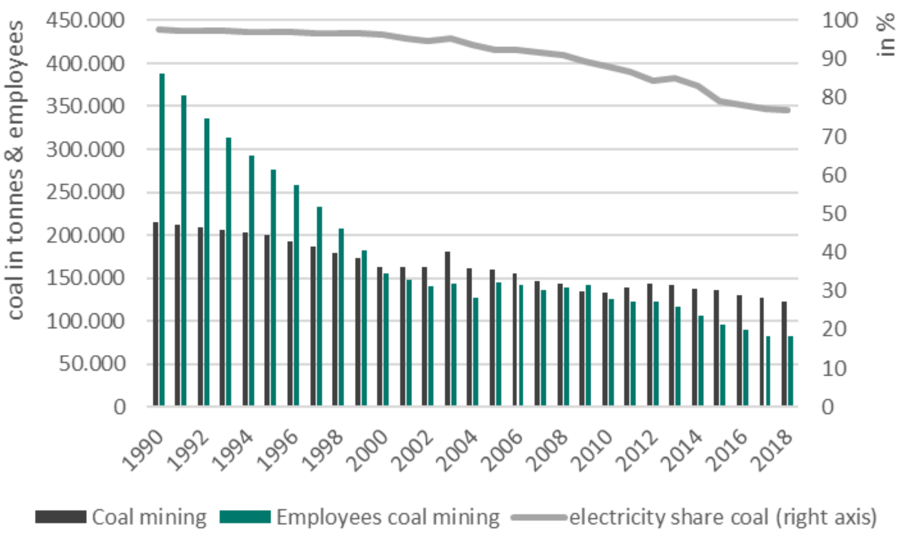

Figure 3-1: Coal mining, electricity generation and number of employees in Poland from 1990-2018.

Source: Authors' illustration based on Central Statistical Office of Poland (various years; 2019), World Bank (2017), and own calculations.

Reductions in coal mining and employment continued during the 2000s, however, much more slowly (see Figure 3-1 for an overview of coal mining, and coal related employment and electricity generation). Unions continued to protest against the shutdown of mines, e.g. in January 2015, after the announcement of the closure of four loss-generating mines owned by KW[18], employees went on strike. Only after the parliament agreed on a special bill to restructure the coal mines to prevent closures did the protests cease. Strikes restarted only days later when JSW[19] announced that the number of miners' working days would be increased and their benefits cut.[20]

The PiS party ('Law and Justice' party) has a strong pro-coal stance (Osička et al. 2020), and won the parliamentary election in 2015[21] partly on promises to protect the coal industry. Under the new PiS government, (partly) state-owned utilities were forced to form the new mining group PGG, rescuing various other mining companies from bankruptcy (EIA 2016; Ancygier and Szulecki 2016). As a consequence, PGG bought KW, formerly Europe's largest coal mining company, and later merged with KHW[22]. The debt of the entire coal sector amounted to around €3.4 billion at the end of October 2015. Additional financial support for PGG emerged from state-owned investors PGNiG, PGE, Enea, Energa

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[18] Kompania Weglowa (Polish coal mining company). For information on the mentioned corporations see Appendix 6.2.

[19] Jastrzębska Spółka Węglowa (Polish coal mining company).

[20] Czarzasty, Jan. 2017. 'Poland: Tensions in Coal-Mining Escalate into Major Conflict'. Eurofound. May 19. https://www.eurofound.europa.eu/observatories/eurwork/articles/industrial-relations/polandtensions-in-coal-mining-escalate-into-major-conflict.

[21] As well as the parliamentary elections in 2019.

[22] Katowicki Holding Węglowy (Polish coal mining company).

and TF Silesia, creating an even stronger link between mining and electricity generation (Polityka Insight 2017; Kuchler and Bridge 2018).

Polish public opinion on coal mining is split: In several referendums of villages affected by mine openings, the majority of citizens voted against new coal mines (e.g. 2009 in Gubin and Brody) (Widera, Kasztelewicz, and Ptak 2016). In other communities where mine openings were under discussion, public acceptance for coal mine development was high (Badera and Kocoń 2014). Factors influencing public opinion are especially fears with respect to employment losses, rising energy prices and energy security. Fuel poverty in Poland is high, and fears persist that reducing coal consumption might increase electricity prices further (Bouzarovski and Tirado Herrero 2017). High energy security concerns are mostly linked to dependence on Russia (Szabo and Fabok 2020; Szulecki 2020; Szulecki and Kusznir 2018). Those concerns are often related to natural gas consumption, but also an important argument mentioned in favour of continuing Polish coal production (Szulecki and Kusznir 2018; Kuchler and Bridge 2018). The Green Party and Greenpeace also refer to energy security concerns regarding Russia, stating that only renewables would reduce this dependence long-term (Szulecki and Kusznir 2018).

Surveys show that Polish citizens are less interested in the economic situation of the coal industry than in energy affordability and energy security.[23] Coal-based energy is not the preferred energy source of the future; instead, the majority of people favour renewable energies and to a lesser extent nuclear energy. Similarly, subsidies towards the coal sector are increasingly unpopular. Only around one-quarter support the social privileges to miners and 64% want coal mines to receive the same treatment as other companies (Bukowski et al. 2015). At the same time, there are parts of society that would support trade unions in a conflict over mine closures with national policymakers (Szpor and Witajewski-Baltvilks 2016).

The interplay between the political agenda, media and public opinion is complex (Osička et al. 2020). However, generally stated, public opinion is influenced by the media. Independent media can enable civil society and science to disseminate their findings and thereby inform the general public and assert pressure on incumbents.

State controlled media, on the other hand, has the potential to strengthen socio-political protection of an (uneconomic) industry regime opposing phase-out processes. State-owned media companies in Poland tend to reproduce state-level policymakers' views (Schwartzkopff and Schulz 2017). Partisanship of the media has traditionally been high in Poland. Polish state-owned media companies receive a large share of their revenue from other state-owned companies through state advertisement funds. Since the election of PiS in 2015, senior management of major state media radio and TV channels can be appointed by the government (Kundzewicz, Painter, and Kundzewicz 2019), increasing partisanship (Dzięciołowski 2017). Progressive voices and regime critics speak only occasionally in mass media and more often in specialised media (Schwartzkopff and Schulz 2017).[24] Polish media focuses on the

[23] See e.g. CEM Institute. 2015. Polish people's attitudes towards the coal industry (Polacy wobec przemysłu górniczego). Cited in: Bukowski et al. (2015).

[24] In the Freedom House ranking, Poland's "Press Freedom Status" was degraded in 2018 from "free" to "partly free", https://freedomhouse.org/report/freedom-world/2018/poland.

importance of coal for the Polish economy and society, highlights energy security concerns and mobilises support for the industry. Often the future of coal is discussed as in how the government needs to keep the coal industry alive, despite its uncompetitiveness (Osička et al. 2020). Climate change and related policy has been covered less than in other EU countries; Politicians speak out less about climate change and do not refer to or downplay the link between coal and climate change (Kundzewicz, Painter, and Kundzewicz 2019).

The only actor group actively working against coal mining and power plants are, increasingly, NGOs like Greenpeace, "Development Yes – Open Pit Mines No!", Action Democracy or Client Earth. As the government is backing coal, more lawsuits are being filed to stop the expansion of new mines and construction of new power plants.

Climate change concerns are not as strong as in most other EU countries (Ceglarz, Benestad, and Kundzewicz 2018; Kundzewicz, Painter, and Kundzewicz 2019). Opposition to coal therefore arises mainly due to relocation of citizens and air pollution. The poor air quality led to a ban of coal furnaces for household heating in Krakow taking effect in 2019. However, the media discourse focuses on smog related to local heating, and mostly not on coal mining and large-scale coal-fired power plants (Osička et al. 2020). Nevertheless, due to the high air pollution levels in Poland (World Health Organization 2016), awareness about the topic is generally high. A survey found that Polish citizens believe that a "lack of policy coherence for sustainable development in terms of air protection" is one of the greatest barriers for the use of renewable energies (Wojciechowska-Solis 2018).

Chandler et al. (2018) categorised actors in environmental and energy policies in Poland according to their position on coal and political power. According to the analysis, NGOs remain weak political actors, ranking far behind incumbent energy companies and political parties in terms of political power. Polish NGOs are relatively small and lack experience in applying for (EU) grants. Difficulties are enhanced by high costs of employment and the absence of national funds supporting NGOs (Wagner, Grobelski, and Harembski 2016; Szpor and Ziółkowska 2018). Hence, as those actors in support of a decline of coal use have less political power, they can influence decision making less than pro coal forces.

3.3.2 Economic environment analysis of Polish coal industry

The Polish coal sector is in a dire financial situation. Without direct subsidies and government enforced bailouts, there would hardly be any hard coal mining left within Poland: Problems persist with profitability and liquidity in the hard coal mining sector leading to bankruptcies (Vaněk et al. 2017; Jonek Kowalska 2015; Kuchler and Bridge 2018). The lignite sector is still generating (at least small) revenues; but lignite reserves in currently operating mines are shrinking. Also, the economics of coal-fired power plants is eroding, partly because of rising CO_2 prices (CTI 2018).

Poor grid infrastructure and missing installed capacities to cover the entire electricity demand are further aggravating the difficult situation of the Polish energy system. Power cuts happened during the summer of 2015, with further outages expected for the next years (Wierzbowski, Filipiak, and Lyzwa 2017). More than 50% of the total installed capacity is expected to come offline between 2020 and 2035, including many coal power plants (RAP 2018), making new investments necessary.

Hard coal exports have decreased from more than 30 million tonnes in 1995 to less than 7 million tonnes in 2017 (Szpor and Ziółkowska 2018; Alves Dias et al. 2018). Hard coal imports increased to more than 10 million tonnes in 2017 (Statistics Poland 2018), which makes Poland a (small) net coal importer, mainly from Russia.[25] Domestic coal extraction costs are higher than the costs of importing coal, mostly due to difficult geological and mining conditions as well as the comparatively low calorific value. Analysis shows that average productivity of hard coal production in Poland decreased by 50% from 2005-2013 (Rybak and Rybak 2016).

Despite the financial problems threatening several companies with bankruptcy and expected cost increases for both hard coal and lignite (Baran et al. 2018), the Polish hard coal and lignite mining industry sets hopes in the small net profits made in 2017 by several of the coal mining companies (e.g. PGG, JSW, PGE). However, other mining companies are still generating losses and consider closing further mines (e.g. Tauron). In March 2020, Polish climate minister therefore mentioned for the first time the option of rearranging assets of state-run energy groups (PGE, Tauron, Enea and Energa), similar to the German example of RWE and E.ON.[26]

Investment plans for a new coal-fired power plant (Ostrołęka C, 1 GW) existed as part of the government's energy security plan in 2019. Latest news from February 2020, however, have led to a suspension due to financial problems. It remains unclear if the plant will ever be built or whether it might be transformed into a gas power plant.[27] Without capacity payments, which will be ruled out under EU law for plants emitting more than 550 gCO_2/kWh Regulation (EU) 2019/943 Article 22(4)[28], estimates suggest that investors including Enea and Energa could lose up to €1.7 billion (net present value) (CTI 2018). The new EU standard will apply for all new power stations as soon as it enters into force and as of July 2025 for all existing power plants. However, Poland managed to introduce a "grandfathering clause", which allows the payment of power plants for capacity provision for all contracts approved before 31 December 2019, regardless of the 550 gCO_2/kWh rule. In effect, this enables Poland to continue to subsidise coal-fired power plants.[29]

[25] The Atlantic coal market is mostly dominated by hard coal from Russia, USA, Colombia and South-Africa (Oei and Mendelevitch 2019). Entering the Baltic Sea, however, increases the costs for potential coal deliveries to Poland. The majority of imported coal in Poland therefore originates from the cheapest exporter Russia. In 2015, the price per ton of Polish hard coal was ~260 PLN, while the price of coal from Russia was only ~180 PLN (Kamola-Cieślik 2017).

[26] Reuters. 2020. Polish utilities may consider German-style reorganization: minister, 12 March 2020. https://www.reuters.com/article/us-climate-change-poland/polish-utilities-may-consider-german-style-reorganization-minister-idUSKBN20Z2HD.

[27] Forbes. 2020. Polish Firms Suspend Financing for New Coal Plant, in Latest Sign That King Coal is Slipping. 15 February 2020. https://www.forbes.com/sites/scottcarpenter/2020/02/15/polish-firms-suspend-financing-for-new-coal-plant-latest-sign-that-king-coal-is-slipping/#93bd0f019373.

[28] Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0943&from=EN.

[29] Euractiv. 2018. 'EU Forges Deal on Coal Phase-out, with Special Polish Clause', 19 December 2018. https://www.euractiv.com/section/electricity/news/eu-hammers-deal-on-coal-phase-out-with-special-polish-clause/.

Polish coal has still no major competition in the electricity sector, with only slowly improving market shares of wind energy and natural gas (renewables <15% share in electricity production, solar <1% and natural gas ~7% in 2018[30]). Reasons include hindering renewable regulations and a strong political focus on energy security and independence of Russia (Kuchler and Bridge 2018) (see also Appendix 6.2, Figure 6-2). To lower dependence on the Russian gas, Poland build a state-owned Liquefied Natural Gas (LNG) terminal, to important gas e.g. from Norway or the MENA region. High utilisation rates despite a price premium compared to Russian pipeline gas prices are another example for the strong ambition by the Polish state for independence of Russia (Szabo and Fabok 2020). Adding biomass to coal-fired power plants was a (temporary) cheap way of lowering specific emissions per kWh and helped Poland to achieve its (relatively low) renewable energy targets (Piwowar and Dzikuć 2016). However, the renewable energy target of a 15% share of overall gross final energy consumption for 2020 will most likely not be met (Janeiro and Resch 2017).

3.3.3 External and internal response strategies of the coal regime

The discourse on the importance of coal mining and combustion is not only enforced by the sector's companies but also by policymakers, the media and trade unions (Świątkiewicz-Mośny and Wagner 2012). In general, the government's influence on coal is strong – especially in the (partly) state-owned companies: When energy companies and mines were merged (see section 3.3.1), the organisational changes entailed the replacement of management staff with party officials. Zientara (2009) describes how these former politicians lacked economic as well as business knowledge and skills and instead were colluding with labour union leaders. Additionally, costs were manipulated and the financial losses were covered up. The interconnection between the government and energy company management was able to enforce the decision to write off most of the industry's debt (Zientara 2009). Within the first months after the 2015 elections, the PiS-led government replaced the managers of almost all state-run energy companies, in which the Treasury holds stakes of at least 50%. This has further politicised the energy sector (Vasev 2017). The Polish Treasury and since 2016 the Prime Minister has ownership rights over the partly state-owned companies PGE, Tauron, Enea and Energa.

The influence between politicians and firms involved in coal, however, works in both directions. The large energy utilities are often consulted when changing laws, while representatives of renewable energy or environmental groups are excluded (Szulecki 2017). Additionally, personal links between the energy corporations and the government (revolving-door principle) increase the influence of the coal regime on policy outcomes (Szulecki 2017; 2018). With a continuing coal dependency from the power and heating sector, mining companies can demand further political and financial support by the government, especially as the main alternative would be importing more Russian coal. The substantial number of employees in energy utilities and mining companies and their supporters can exert indirect pressures on policymakers in the form of election votes (Chandler, Kassenberg, and Hille 2018), especially in local ones.

[30] https://www.statista.com/statistics/1003292/poland-power-production-by-fuel/.

The energy utilities have formed alliances in the past to achieve favourable regulation. The four biggest electricity companies, e.g., formed a bloc opposing any changes to the Energy Act in 2013 law that would improve conditions for distributed renewable energy and, hence, potentially threaten their secure market position (Skjærseth 2014). One argument that coal-based utilities have frequently used is that the lack of high-voltage power lines and an insufficiently developed electricity grid would not allow for an expansion of distributed renewable energy resources (Szulecki, Ancygier, and Szwed 2015). Among the coal mining companies seemingly making progress in restructuring efforts is JSW. The corporation has replaced its management board and after transferring one of its seven mines to the restructuring company in 2017 and selling some of its assets, it has been making net profit in 2017, following years of net loss (Jastrzębska Spółka Węglowa SA 2018). As a measure to save money, the company stopped providing social benefits like bonuses and free coal for employees between 2016 and 2018. In June 2019, the CEO of JSW was fired after a dispute with the Polish energy ministry, including the refusal to buy a hard coal mine from struggling state-owned energy utility and mining company Tauron.[31]

As societal acceptance for the expansion of lignite opencasts was eroding, operators of lignite mines developed new strategies to gain public support. For example, information points and meetings as well as other participatory structures were set up to involve local citizens more in decision-making processes (Badera and Kocoń 2014). However, this served mainly as an information tool for companies that would not only learn more about the motives and aims of citizen groups, but also use this knowledge to prepare targeted response strategies (Wagner, Grobelski, and Harembski 2016).

Both hard coal and lignite companies have developed Corporate Social Responsibility (CSR) strategies, at least after they became mandatory in January 2017. As they see their business model threatened by “an uncertain political situation, many media attacks and unfavourable public opinion”, they use CSR as a strategy to improve their public image (Pactwa and Woźniak 2017). Additionally, coal is often rebranded as “clean coal” to create an image of coal being a long-term solution compatible with climate protection (Kuchler and Bridge 2018). Some energy firms start to implement more structural changes: The largest electricity utility PGE (majority state-owned), e.g., starts to invest in several onshore and offshore wind farms.[32]

Polish policy makers are, besides setting favourable domestic regulation for the coal industry, also responding to the external environment. This can especially be seen by their attempts to influence and soften EU regulation (e.g. air pollution standards and CO_2 pricing mechanisms) to protect the Polish coal industry: The dependence on coal played an important role in creating opposition to EU climate policies (Braun 2014; Zapletalová and Komínková 2020). Polish influence on EU climate policies has been increasingly assertive, partly in coalition with other Central and Eastern European countries (Bocquillon and Maltby 2017; Zapletalová and Komínková 2020). Poland aimed to lower ambition

[31] https://www.mining.com/web/poland-sacks-ceo-of-state-run-coal-miner-jsw-shares-tumble/.

[32] PGE. 2020. ‘PGE in Transition’. https://www.gkpge.pl/investor-relations/content/download/5473/file/PGE%20in%20transition_January_II%202020.pdf.

especially in the case of the EU GHG targets for 2020 and 2030, the EU ETS reforms, argued against country specific renewable energy targets, and blocked conclusions on the Low Carbon Roadmap for 2050 (Bocquillon and Maltby 2017; Marcinkiewicz and Tosun 2015; Skjærseth 2016). Vetoes on EU common energy and climate policy were justified by stating that the resulting economic costs would be too high (Creutzig et al. 2014; Skjærseth 2016).

3.4 Discussion

3.4.1 Continuing Polish coal industry incumbency

Changing the status quo will be challenging: Coal has structural power over the Polish state, as it relies on coal for electricity and heat provision, tax revenues, employment, and support for coal at least partly influences election results. Increasingly, coal corporations use also more internally-oriented responses (changing aspects within the corporation in contrary to influencing the economic or socio-political environments). They have, for example, abolished miners' privileges, replaced management boards, liquidated several mines, limited production from remaining ones and started the diversification of some electricity utilities towards more natural gas and renewable energies. However, both externally-oriented and internally-oriented strategies energy generation and coal mining firms still aim mostly at securing coal's future in Poland's and the corporations' energy mix. Despite dwindling available resources, international decarbonisation efforts and renewable energy expansion commitments, the main corporate response strategies are: lobbying for favourable legislation for coal, lobbying against support for renewables, creating a discourse about coal being necessary for energy security and the economic development of Poland as well as possibilities for so-called 'clean coal' technologies. This includes revolving-doors between government ministries and energy corporations, CSR policies and media campaigns. Common requirements of the *economic environment* like economic competitiveness, efficiency and financial performance, have – so far – only played a subordinate role, made possible through state-ownership. The *socio-political* environment still legitimises coal; however, parts of civil society's acceptance of coal is declining.

Negative experiences with restructuring programmes, especially during the late 1990s, created opposition by unions and citizens to exit coal. The analysis above as well as previous analyses have shown that the entanglement of the government with mining and electricity corporations as well as unions led to the protection of a sector that has been unprofitable for decades (Zientara 2007; 2009). Until now, there appears to be no clear governmental strategy on how to reduce the dependence on coal. The newest NECP, however, acknowledges parts of this shortcoming and outlines future work within this area (gov.PL 2019).

A challenge for the Polish energy sector will be to refurbish the aging power plant fleet. This will need major investments – no matter whether they will be in coal, natural gas, nuclear or renewables. The government, however, struggles with their preferred option of new coal power plants – due to stricter European regulations and little interest from investors that are too afraid of potential stranded assets (Löffler et al. 2019; Gerbaulet et al. 2019). Also, the vision of nuclear appears very unlikely observing rising costs of ongoing constructions in the UK, France or Finland (Schneider et al. 2019). This leaves only two options: Natural gas – which would potentially mean an increasing dependence on Russia and relying on a fossil fuel that needs to be phased out under EU climate neutrality targets by 2050 – or renewables.

A barrier for renewable instalments (in comparison to conventional power sources) are its division of costs, consisting of high investment costs and very low residual operating costs (Hirth and Steckel 2016). Furthermore, as most coal-based electricity was distributed centrally from Silesia to the rest of Poland, much of the Polish electricity system would need to be redesigned (Szabo and Fabok 2020). This results in a need for high upfront funding, exceeding the planned investments by the Polish government, which would pay-off in the medium and long run. Additional external financial volumes from the EU – e.g. through the expected 'European Green Deal' (EC 2019c) – or private investors are therefore needed to start of a successful energy transition in Poland.

Table 3-1 summarises drivers and barriers identified through the TEF analysis for a reduction of coal's dominance. Coal miners and company board members have high political influence; citizens' support persists because of fears about rising energy prices if coal would be pushed out of the market also due to limited access to information about renewables and NGOs have limited influence. Coal has still no major competition on the electricity market. The coal regime remains protected as jobs, energy security, political and corporate power all depend on it. The only actor group actively working against coal is NGOs. Their main argument hereby concentrates on the reduction of air pollution, or in some cases other environmental issues. Climate protection, on the other side, is of much lower concern to the majority of population. The main political driver for a coal phase-out is hereby the EU, with a mix of regulations weakening the already bad economic condition of the coal industry as well as policies supporting alternative industries.

Table 3-1: Drivers and barriers for a reduction in Polish coal production and consumption.

Drivers	Barriers
Economic Factors	
Limited economic feasibility of domestic hard coal mining. (+++)	Regional economic dependence and high employment share in the coal sector. (—)
Limited economic feasibility of new coal-fired power plants. (+++)	Limited financial support mechanisms for renewables (need for upfront investment). (—)
Aging infrastructure of power plants and the electricity grid and limited domestic coal resources in still operating mines. (+++)	Potentially rising (household) electricity prices in the short-term. (—)
Reduction of load factors due to cheaper electricity imports. (++)	No need for corporations to make profits as the state does not expect them to be competitive. (—)
Increasing competition of renewables (including potential offshore wind farms) and natural gas (availability of LNG imports). (++)	Restricted government budget for new investments in renewables, structural policy programs, etc. (–)
EU ETS: fewer free certificates and rising CO_2 prices. (+)	
Political & Legislative Factors	
Power plants breaching EU emission limits (Industrial Emissions Directive, IED). (+++)	Energy security concerns (about energy imports and perceived unreliability of RES). (—)
(Conditional) Financial incentives from the EU for the instalment of renewables and cohesion policies to help carbon intensive regions. (+++)	Government in favour of continuing high coal dependency (bail-out of bankrupt companies, subsidies, capacity market, etc.). (—)
Increasing pressure by the EU: Ban on coal mining subsidies, restriction of capacity markets, climate policies, etc. (++)	Vested interests and high political influence of coal companies. (—)
Rising international pressure on coal. (+)	High political influence of coal labour unions. (—)
	Investments in and discourse of "clean coal" technologies. (-)
Social & Environmental Factors	
(Local) protests due to air and water pollution and against new mine openings. (+)	Fear of change and loss especially in coal regions (energy poverty levels, past negative restructuring experiences, etc.). (—)
(International) climate change concerns. (+)	Ideology and culture: Belief that growth is only possible with coal, that coal is central to development, defining national and regional identities. (—)

Note: For drivers and for barriers the (+), (++), (+++) and (-), (–), (—) indication illustrates the relative strength of the impact, respectively. That an equal number of drivers and barriers is included in the table does not mean that they have an identical weight. To date, the barriers still dominate the drivers of a coal phase-out. While economic drivers and EU legislation are the main points weakening the coal regime, political and ideological reasons are the main identified barriers for an end to coal production and consumption.

3.4.2 Possible future policies to reduce coal's importance

The analysis suggests that for a Polish pathway towards less reliance on coal, external pressures (e.g. legislation by the EU or falling renewable energy prices, see Table 3-1) – in addition to domestic pressure, so far mostly by NGOs – will be necessary, as the majority of powerful Polish actors are still in favour of continuing coal consumption.

The European Union serves as spokesperson for the international climate targets signed within the Paris Agreement, especially after the announcement of the US to step aside. The European Commission has announced to reduce emissions in Europe by 50-55% by 2030 (compared to 1990) and to reach full carbon neutrality by 2050 (EC 2019c). A necessary condition for these targets is the phase-out of Polish coal sector. The European Union hereby uses a strategy of 'sticks and carrots' to incentivize an energy transition in Poland: i) stricter climate and environmental regulation to reduce coal consumption as well as ii) (conditional) financial incentives for the instalment of renewables and most important cohesion policies to help carbon intensive regions. An example of this is the 'European Green Deal' which could provide support of up to 2 billion € to Poland, conditional on the promise of carbon neutrality.[33]

A policy discussion needs to take into account political feasibility as one of the most important aspects. Going back to textbook first best examples like carbon taxes or moratoria seem unrealistic in the context of the political economy of coal. It is therefore important to account for policy errors, to include upscaling mechanisms, to think about policy-learning and sequencing while at the same time creating planning security and credibility (Purkus, Gawel, and Thrän 2017; Kern and Rogge 2018). Additionally, for a successful transition, policies need to include anticipatory, long-term planning and to combine supply and demand policy options as well as one focused on social aspects next to climate impacts (Spencer et al. 2018).

As discussed in section 3.2, a destabilisation of a regime occurs when more and more pressures align. Both the identified drivers and barriers (see Table 3-1) should be addressed simultaneously when designing concrete policy packages. When looking at policy outcomes regarding coal since the 1990s, policy objectives focus on energy security before anything else, while sustainability and climate change concerns rank quite low. Therefore, any policy targeting GHG emission reductions, at least in the beginning, needs to be coupled with other policies with different objectives, like lowering energy import dependence or energy poverty levels, increasing jobs in other sectors or at least address their influence on any of these aspects.

As part of a more sustainable energy strategy[34], the Polish government might therefore include coal phase-out and renewables phase-in policies, structural policies aiming to increase social security and innovations support to create regions fit for the future in a new policy mix. Table 3-2 includes therefore

[33] Euractiv 2020. „Gerechte Energiewende": Wer kriegt die EU-Gelder? 27 February 2020. https://www.euractiv.de/section/energie-und-umwelt/news/gerechte-energiewende-wer-kriegt-eu-gelder/.

[34] A draft for the Polish Energy Plan until 2040 was presented in November 2018 with continued support for coal and very limited support for renewables.

measures out of the climate policy toolkit (Green and Denniss 2018, Table 1), complemented by structural policy measures, addressing the identified drivers and barriers:

Table 3-2: Overview of policies addressing specific drivers and barriers of Poland's political economy of coal.

	Restrictive Policies	Mix	Supportive Policies
Supply Side Policies	**Restructuring of the remaining coal mining sector and subsidies** Reducing and eventually stopping financial support could end domestic production of coal before 2040* (Bukowski et al., 2015). A continuous phase-out plan like e.g. in the UK or Germany (with production quotas or specified years for mine closures) could increase planning security for all affected actors. Our analysis shows that a stronger policy like an immediate moratorium on coal mining is currently politically infeasible. • *Addressing **drivers** of financial problems of the coal industry, limited coal resources in already operating mines, pressure from the EU banning coal subsidies, international pressure to phase-out coal as well as concerns due to climate change, air and water pollution.* • *Reducing barrier of limited financial resources by freeing state money that could be redirected to renewables or structural/social programmes.*	**Diversifying corporations** As most corporations are state-owned, obligations for a minimum diversification of energy sources can be implemented: could encourage a process from coal mining towards more sustainable industries. • *Using the **drivers** of increasing competition from renewables and natural gas, as well as the electricity capacity gap, rising CO_2 prices and societal concerns about climate change, air and water pollution* • *Might contribute to reducing **barriers** of rising electricity prices, energy security and lower concerns by civil society about negative consequences related to reducing coal production.*	**Renewables phase-in** Pointing out how dwindling domestic coal resources would make Poland import dependent in the medium term future, and that ~50% of the total installed electricity capacity comes offline between 2020-2035 could serve as a justification for more renewable energy support (e.g. feed-in-tariffs, revoking of law from 2016 restricting wind power expansion**, investment of state owned-companies in renewables). Domestic production of renewable energy related technologies or development of auxiliary services could create prosperity and knowledge apart from coal. • *Addressing **drivers** of increasing competition by renewables, electricity capacity gap after 2020, coal power plants breaching EU emission levels, concerns about climate change, general pressures to phase-out coal open up space for renewables.* • *Need to overcome **barrier** of limited support mechanisms for renewables; renewables incorporating a larger market share could increase pressure for coal companies to be competitive and reduce fears about unreliability of RES.*
Demand Side & Structural Policies	**Restructuring of coal-based electricity generation** Limiting financial support and subsidies for coal power plants. No support for 'clean coal' projects or further modernisation. Being part of the EU means that tighter emission standards e.g. enforcement of already decided emission limits (IED), limited capacity payments (e.g. a ban on capacity payments for generation with more than 550 g CO_2/kWh), increasing CO_2 prices, etc. need to be implemented. • *Addressing **drivers** of financial problems of existing coal-fired power plants, increasing competition of renewables and natural gas, as well as EU emission limits, rising CO_2 prices and societal concerns with respect to climate change, air and water pollution.* • *Might contribute to reducing **barrier** of unnecessary investment in so called "clean coal" technologies.*		**Social and structural policy measures** A socially acceptable coal phase-out needs to prevent electricity price increases for low-income households. Negotiations with trade unions can result in a social security programme including the creation of new, well-paid jobs, a reliable social security net, retraining programmes and job search support. Support for former coal regions needs to increase their capacity to diversify the local economy and create more resilient, attractive and competitive regions. Local authorities need sufficient funds and capacity training for implementation.*** Household coal demand can be reduced e.g. by subsidies for building refurbishments or shift from coal heating to alternatives like heat pumps. • *Addressing **driver** of air pollution concerns.* • *Contribution to reducing the **barrier** of fears of workers and citizens about negative impacts for the region and themselves.*

*Notes: * This is not to say that 2040 should be the target year. Analysis has shown that compliance with the Paris Agreement would require an EU-wide coal phase-out by 2030* (Climate Analytics 2017). *** Polish Act on Investments in Wind Power Plants (Sejm paper no. 961/2016). *** See Brauers et al.* (2018) *for dimensions for a just transition in coal regions.*

3.5 Conclusions and policy implications

The aim of the paper was to analyse the political economy of coal in Poland for three decades from 1990 until 2019, identifying reasons for the persistence of the coal regime, but also identifying potential avenues for change. Besides examining which actors are supporting coal and who benefits from coal production and electricity generation, the paper identified key barriers (factors stabilising the current status quo) and drivers (initial factors that are destabilising the coal regime) using the Triple Embeddedness Framework. By separating socio-political aspects from economic aspects, it allows to distinguish between the main influencing factors of the different contexts. These partly work in opposite directions in Poland: The socio-political considerations mostly argue in favour of the continued use of coal, while most economic considerations are an argument for a decline or phase-out of coal. Additionally, the framework shows how the coal regime responds to the pressures from the two environments, highlighting their so far successful strategies to prevent major changes to coal use and mining in Poland. Based on these findings, policy options to support the existing drivers and reduce barriers of reducing coal's dominance were discussed.

Resistance to a shift away from coal exists mainly due to the deep incumbency of the coal industry and a supportive government. Vested interests of the coal regime are protected due to strong links between coal corporations and the government. Most coal corporations are majority state owned and unions are highly involved in political decisions. This makes it more difficult for coal opposing voices to weaken the political support for coal. The main arguments put forward against a coal phase-out are similar to other countries and include aspects of energy security, energy independency concerns, fears of rising energy prices, concerns about the reliability of renewables and the prospect of unemployment in regions mainly dependent on the coal industry. Other specifics for Poland - locking the country even deeper into its dependence on coal - are past negative restructuring experiences, strong concerns about relying on Russia's energy resources, little influence by environmental NGOs, and limited financial strengths to experiment with new investments.

We conclude that the socio-political environment of Poland still favours coal and therefore limits the potentially negative impact of the economic environment by protecting the coal regime. However, as restructuring efforts by coal corporations are increasing, their strategies shift from targeting temporary problems to structural ones. Nevertheless, a deep-restructuring of core beliefs, identities and values within the country is still pending. So far, the production and use of coal is linked in political discussions as well as in most media coverage to the functioning and prosperity of the entire Polish economy (see Newell and Paterson (1998) and Newell (2018) for structural power of fossil fuel corporations through connections of energy with economic growth). A limited but increasing amount of studies and news headlines, however, starts to point out the existing potential for a growth of renewable energies, resulting also in additional job opportunities.

There are several internal drivers that might decrease coal's dominance in the future: Among them limited economic feasibility of domestic hard coal mining and of new coal-fired power plants, dwindling resources in currently open lignite mines, aging energy infrastructure as well as increasing competition by natural gas, renewables, and cheaper electricity imports, but also increasing public protests. Additionally, external pressures by the European Union are growing: This becomes apparent e.g. within the discussions surrounding the 'European Green Deal' and the push towards climate neutrality by 2050 (EC 2019c). The EU hereby pairs stronger environmental and climate regulation with additional (conditional) incentives in the form of cohesion policies to enable a 'just transition' of carbon intensive regions leaving no one behind.

The need for energy security is deeply engrained in Polish politics, so that no change will be possible without changing the belief that a secure and affordable energy supply is possible without (a large amount of) coal – especially as domestic renewables also increase energy security. To be part of the EU's ongoing energy transition, Polish policies aiming at reducing coal production should be included in policy packages bundled with renewable phase-in policies and structural policies addressing the related negative social impacts. Important positive and negative lessons can hereby be learned from other international examples, e.g. structural policy programs guiding the phase-out of coal mining in Germany since the 1960s (Oei, Brauers, and Herpich 2019; Stognief et al. 2019), long-lasting unemployment effects in former coal mining areas in the United Kingdom (Fothergill 2017), and just transition approaches addressing interests from labour and affected regions in negotiated settlements in Spain (Rentier, Lelieveldt, and Kramer 2019).

Poland is, like e.g. Spain, a coordinated market economy (CME), where a major share of coal assets are owned and managed by the state (Rentier, Lelieveldt, and Kramer 2019). The research by Rentier et al. (2019) shows that in this case, decisions about the phase-out of coal are "essentially public decisions", as opposed to one left to the electricity market. Decision making is, therefore, more strongly influenced by employment protection concerns and not mainly by competitiveness (in contrast to liberal market economies). However, the example of Spain also shows that social and structural policies can help overcome resistance to phasing-out coal and need to accompany climate policies to achieve a just transition.

The majority of discussed policy measures are aimed at using the identified drivers as well as to reduce the barriers. However, none of these measures directly targets lowering the political influence of the coal industry and unions. Analysing this further would be an interesting research question. Additionally, more specific policies, not just policy fields, tackling the coal industry, should be analysed in-depth. As Poland is an outlier within Europe in how the media covers climate change, and only few publications deal with public opinion about coal, an analysis of the Polish coal discourse and how it influences political decision making would be important. Additionally, identifying and mapping the role of media – in times of increasing social media use and fake-news – can be an important aspect for future advancements and applications of the Triple Embeddedness Frameworks and similar approaches. Finally, a stronger focus should be put on the influence of the EU as external driver pressurising the Polish coal industry and vice versa.

An alignment of rising internal and external pressures has started to destabilise the coalition between a pro-coal government, coal dependent and market dominating upstream and downstream corporations as well as unions. This opens up the floor for more direct policies aiming at reducing coal also in Poland. First signs can be seen within pledges of the main opposition party (Civic Coalition) in their election campaign in July 2019 to phase-out coal use in the energy sector by 2040.

The proposed measures identified by this research could be the start for an increasingly ambitious plan for a just and timely transition of the Polish energy system which:

i) limits its impact on the climate, the environment and human health, and at the same time also
ii) provides energy security, increases competitiveness of the Polish economy and job opportunities, and therefore
iii) becomes a cornerstone within the 'European Green Deal' – leaving no one behind.

Chapter 4

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

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**Published as:* Brauers, Hanna, Isabell Braunger, and Jessica Jewell. 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.

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

Abstract

The German energy transition has been hailed as a role model for climate action. However, plans for the construction of three large-scale Liquefied Natural Gas (LNG) import terminals are receiving strong state support. This is inconsistent with Germany's climate targets, which require a reduction rather than expansion of natural gas consumption. In our paper, we aim to unpack the connection between the risk of natural gas lock-in and the energy transition. We analyse the co-evolution of the techno-economic, socio-technical and political realms of the German natural gas sector and influence of actors within that process. We use a combination of energy system and interview data, and introduce a new approach to triangulate material and actor analysis. We show that four natural gas lock-in mechanisms cause the support for LNG in Germany: (A) the geopolitical influence from the United States, combined with (B) security of supply concerns due to the planned coal and nuclear phase-out, (C) pressure from a wide variety of state and private sector actors, and (D) sunk investments in existing gas infrastructure. Two additional mechanisms supporting the strong position of natural gas are (E) the strength of the emerging synthetic gas niche, and (F) weak opposition against LNG and natural gas. We highlight the severely overlooked lock-in potential and related emissions, which could complicate and decelerate energy transitions as more countries reach a more advanced phase of the energy transition.

Highlights:

- Growing tension exists between natural gas use and climate protection goals.
- Natural gas receives state support, leading to lock-in influencing energy transitions.
- Actors' agency mediates between realms, while also being constrained by them.
- International diplomacy and energy security concerns strengthen gas regime.
- Natural gas regime in Germany remains unchallenged by opposition or competition.

Keywords: Natural gas, lock-in, Germany, energy transitions, co-evolution, meta-theoretical framework

4.1 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). While some present natural gas as a 'bridge technology' (Neumann and Hirschhausen 2015; Ausubel, Grubler, and Nakicenovic 1988),[35] 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).

[35] 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).

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 (Global Energy Monitor 2020).[36] This compares to an LNG trade of 355 MT in 2019 (GIIGNL 2019), an increase of ~45% compared to 2015 (Statista 2020).[37] 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 4-1). 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 other states, Germany has pledged to phase-out coal[38], 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 4.4). 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

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[36] Another 122 MTPA of export capacities and 144 MTPA of import capacities are currently under construction (Global Energy Monitor 2020).

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

[38] Clean Energy Wire. 2020. 'Spelling out the coal exit – Germany's phase-out plan'. https://t1p.de/lq0v.

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.

4.2 Case description

Figure 4-1 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.[39] 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 4-1). Jointly, they represent the case of LNG in Germany, which we analyse in this paper.

[39] 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.

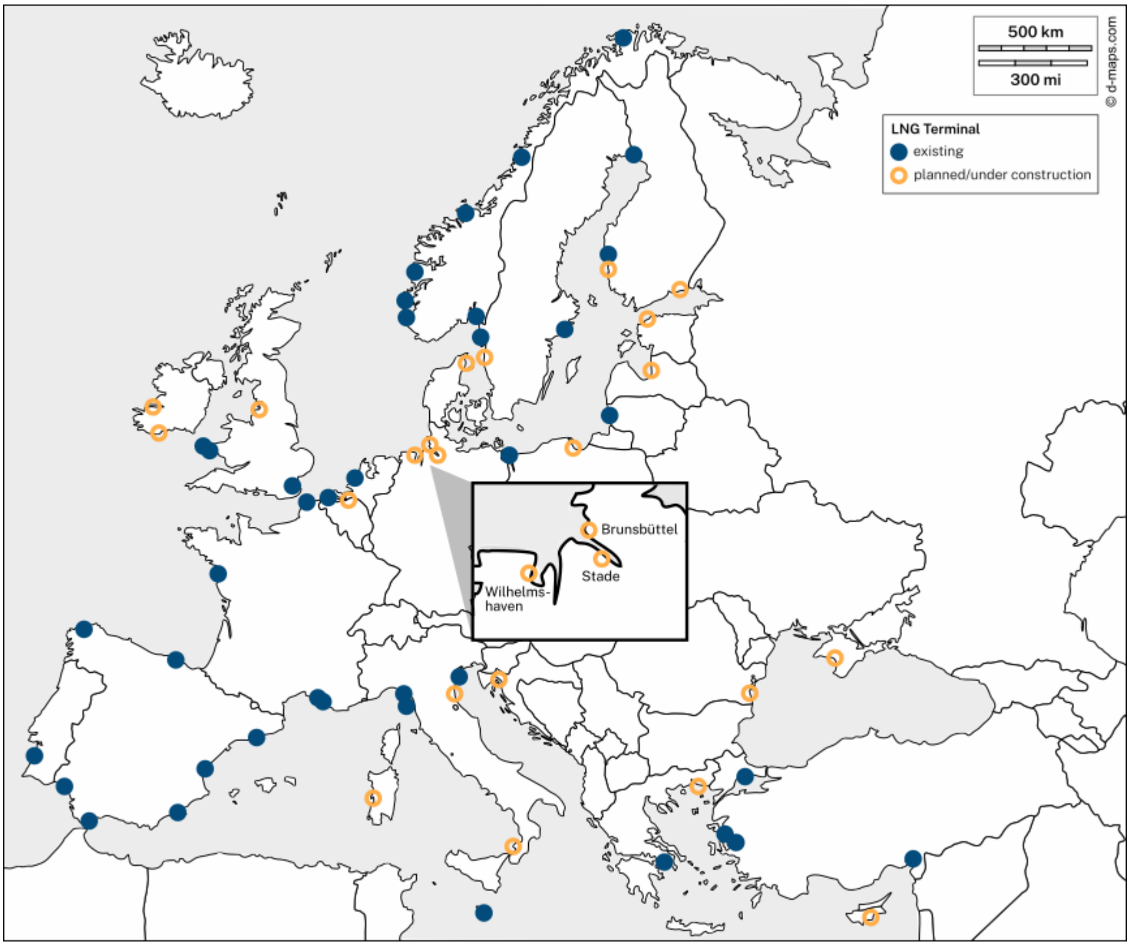

Figure 4-1: Existing and planned LNG terminals in Germany and the EU.

Source: Authors' illustration based on d-maps and the Global Energy Monitor.[40]

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 4-1 and Section 4.6).

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[41] – including e.g. the environmental impact assessment – typically take several years from the initial proposal to the approval, procedural handling, construction, and commissioning. The responsible agencies differ depending on

[40] d-maps. 2021. 'Map Europe'. https://d-maps.com/carte.php?num_car=2233&lang=en and Global Energy Monitor. 2021. 'Europe Gas Tracker'. https://globalenergymonitor.org/projects/europe-gas-tracker/tracker-map/.

[41] In German „Raumordnungsverfahren" and „Planfeststellungsverfahren".

the federal states and are subordinate to different federal state ministries.[42] 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.[43]

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[44] 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[45], 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".[46]

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 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.

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[42] 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'. https://t1p.de/xmdg; Ministerium für Wirtschaft, Verkehr, Arbeit, Technologie und Tourismus Amt für Planfeststellung Verkehr. 2020. 'German LNG-Terminal Brunsbüttel – Beginn Planfeststellungsverfahren'. https://t1p.de/o3ks; Landesbüro Naturschutz Niedersachsen GbR. 2021. 'Beteiligung in Umweltfragen'. https://umwelt-beteiligung-niedersachsen.de/faq-page#n16; LabüN Gbr. 2019. 'Stellungnahme Scoping –Termin'. https://t1p.de/h1gk.

[43] LNG Agentur Niedersachsen. 2020. 'LNG-Entwicklung an der niedersächsischen Nordsee'. https://t1p.de/jszx.

[44] Coalition agreements from 2017 in Lower-Saxony https://t1p.de/9xex and Schleswig-Holstein https://t1p.de/4202.

[45] For an explanation of this concept of Regional Development Policy in Germany see OECD. 2019. 'Regional Development Policy in Germany'. https://www.oecd.org/cfe/_Germany.pdf.

[46] Federal Ministry of Finance. 2020. 'Non Paper Germany Nord Stream 2/U.S. LNG'. https://t1p.de/s7cq.

Table 4-1: Short profile of planned large-scale import LNG terminals in Germany.

	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; 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

Source: (Süddeutsche Zeitung 2019; Stratmann 2019; RWE Supply & Trading GmbH 2018; Oiltanking 2019; Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr 2015; NDR1 Niedersachsen 2018b; 2018a; Maksimenko 2018; German LNG Terminal 2018; Handelsblatt 2018; Dammann 2018; Czechanowski 2019; Boyens Medien 2019; Deutscher Bundestag 2020; Bundesrat 2019; LNG.AGENTUR Niedersachen 2020).

Note: An FSRU is a Floating Storage Regasification Unit.

The LNG terminal in Wilhelmshaven is meant to create around ~50-60 long-term jobs.[47] 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.[48] 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.[49]

4.3 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

[47] GRÜNE Wilhelmshaven. 2021. 'Positionspapier zum LNG-Terminal in Wilhelmshaven'. https://t1p.de/rz45.

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

[49] Ibid.

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 (Cherp et al. 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).[50] 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 dynamics are shaped by both *material realities* and *actor perceptions* (Cherp et al. 2018),[51] 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 4-2):

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

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[50] 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; Fünfschilling and Truffer 2014): transition management (Loorbach 2010), strategic niche management (Kemp, Schot, and Hoogma 1998), the multi-level perspective (Geels 2002), and technological innovation systems (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.

[51] 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.

institutions as formal and informal structures, which shape society (e.g. policies, standards, rules, values) (Fünfschilling 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 (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 infrastructures 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 (Geels et al. 2016; Turnheim et al. 2015; Geels, Berkhout, and Vuuren 2016) is to understand regime resilience (Rip and Kemp 1998; Geels 2002), particularly amidst growing pressure from new(ish) entrants. This connects to what 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. 2020). 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* (Geels 2014c). 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 (Geels 2014c). 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).

Table 4-2: Systemic focus, key concepts and role of lock-in in each realm.

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

One key theoretical question is how these relatively autonomous realms interact. Policies, artefacts and actors all connect and influence the three realms (grey connections in Figure 4-2). 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; Smith, Stirling, and Berkhout 2005; Becker, Beveridge, and Röhring 2016; 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.

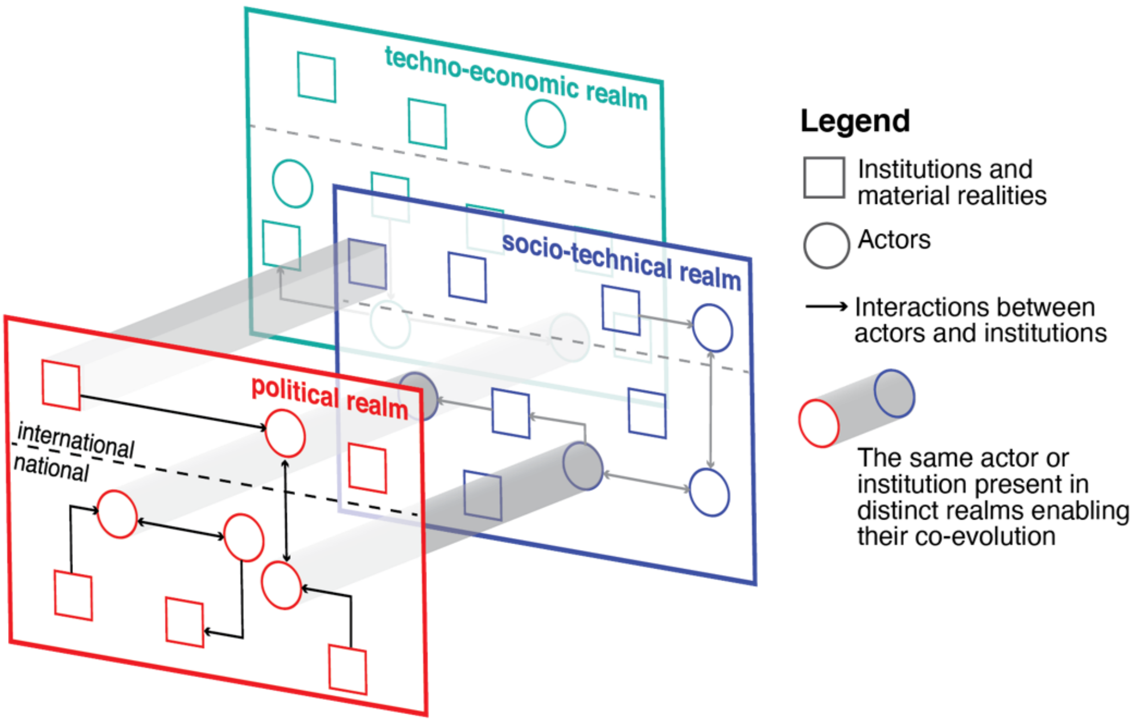

Figure 4-2: Actors influence the realms while the realms define the space for actors' perceptions and related strategic actions.

4.4 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 4.3. 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.

Table 4-3: Main variables covered in respective realms.

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

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

4.4.1 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 4-3).

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 (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).[52] 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).

4.4.2 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).[53] 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.[54]

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.

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[52] Generally, technological innovation processes take place and are influenced on various levels, such as regional, national and international, and those levels interrelate (Binz and Truffer 2017). 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.

[53] 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'.

[54] 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. 2009). Therefore, we aim to present our approach as detailed and transparent as possible.

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 4-3).

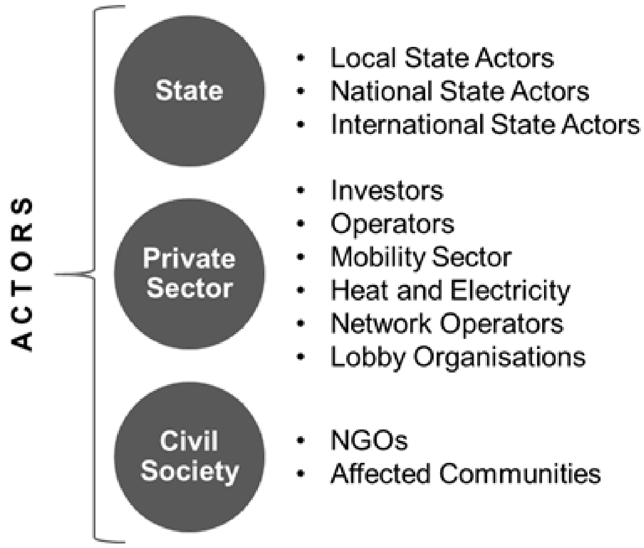

Figure 4-3: Main actor groups involved in the political processes surrounding LNG Terminal construction in Germany.

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 4-4).

Table 4-4: Summary of conducted interviews with acronyms.

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 supportive / 1 opposed
2	Community actor and NGO	Interview_CA	2 opposed
6	Private sector actors	Interview_PSA	3 supportive / 2 non-mobilised / 1 opposed

** 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 2010). 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.

4.4.3 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 4.5) and derive the most relevant mechanisms (Section 4.6), 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?

4.5 Results of realms and actor analysis

The results are structured by realm: Section 4.5.1 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 4.5.2 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

4.5.3 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.

4.5.1 The political realm

4.5.1.1 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 4-4). 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).

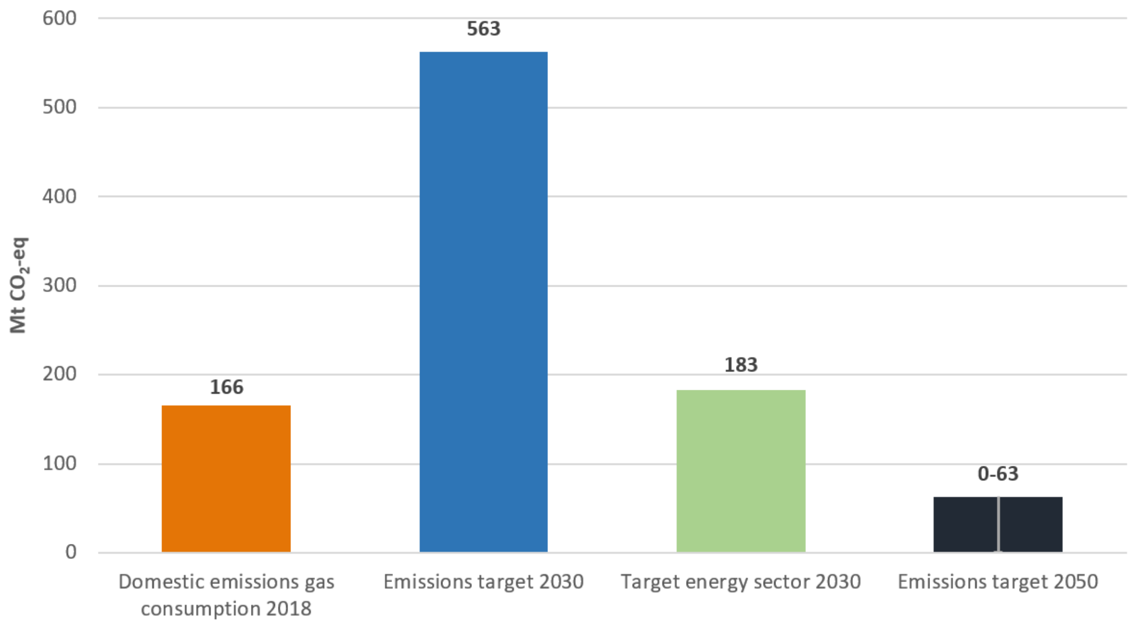

Figure 4-4: Comparison of current emissions from gas consumption and emission reduction targets for Germany.

Source: Authors' illustration based on (Breitkopf 2020), (BMUB 2016), and (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.[55] 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 (Eurostat 2018). 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 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.

4.5.1.2 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

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

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 2019d).[56] 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 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].[57]

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 4.5.2.2). 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].[58] 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

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[56] 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.

[57] 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.

[58] 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'. https://t1p.de/067b.

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 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 4.6). 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).

4.5.2 The techno-economic realm

4.5.2.1 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).[59] In total, natural gas accounts for 24% of Germany’s CO_2-eq emissions.[60]

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[59] Umweltbundesamt. 2021. ‘Energieverbrauch nach Energieträgern und Sektoren’. https://www.umweltbundesamt.de/daten/energie/energieverbrauch-nach-energietraegern-sektoren.

[60] Statista. 2020. ‘Energiebedingte CO_2-Emissionen in Deutschland nach Energieträger im Jahresvergleich 2000 und 2018’. https://t1p.de/84q6.

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).

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).[61] 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.

4.5.2.2 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; Norwegian Petroleum 2019)).

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 (EIA 2019). 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).[62] 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.

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

[62] 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'. https://t1p.de/7mb5.

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 2020a).

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 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 4.5.2.1). 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[63], the exemption of LNG trucks from toll charges, and the creation an official "LNG-Taskforce".[64] However, studies show that switching to LNG in the transport sector does not necessarily lead to a reduction of GHGs (Köhler et al. 2018).[65] Other countries, such as the UK, have decided in their mobility strategy not to consider LNG as a climate friendly fuel option.[66]

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).

4.5.2.3 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

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[63] BFJ. 2019. Energiesteuergesetz. https://t1p.de/ton4; and Zoll. 2019. 'Erdgas als Kraftstoff für Kraftfahrzeuge'. https://t1p.de/gbae.

[64] Dena. 2016. 'Liquefied natural gas: LNG Task force defines work priorities'. https://t1p.de/kgc2. Dena. 2021. 'LNG-Taskforce und Initiative Erdgasmobilität'. https://t1p.de/6fhc.

[65] 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%.

[66] GOV.UK. 2019. 'Written statement to Parliament: Clean maritime plan'. https://t1p.de/0k95.

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 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 (VSHEW 2019).[67]

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).

4.5.3 The socio-technical realm

4.5.3.1 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

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[67] VSHEW. 2019. 'Scharfe Kritik des VSHEW an Förderung des Brunsbütteler Flüssiggasterminals'. Reinbek. https://t1p.de/0fih.

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).[68] Hydrogen has long been promoted as an alternative (see e.g. IEA (2019c) 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 (J. Stern 2019; von Hirschhausen, Praeger, and Kemfert 2020).[69] 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). 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.

4.5.3.2 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.[70] The alliance demands the construction of 5 GW electrolyser

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

[69] 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'. https://t1p.de/1cz7.

[70] Power to X Allianz. 2021. 'Allianzpartner'. https://www.ptx-allianz.de/ueber-uns/allianzpartner/.

capacity[71] by 2025 and changes to regulation to facilitate the market entry of 'Power to X' technologies.[72] Central actors from the renewable industry, like the umbrella association of renewable energy[73], 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.[74] 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 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.

4.6 Mechanisms explaining LNG support in Germany

The main mechanisms to explain political support for LNG terminals are summarised in Figure 4-5. 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 4.3), and those that more generally support natural gas as a technology.

[71] Used to generate hydrogen from electricity.

[72] Power to X Allianz. 2021. '10-Punkte-Plan zur Nationalen Wasserstoffstrategie – Power to X durch Anwendungsoffenheit zum Erfolg führen'. 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.

[73] German Renewable Energy Federation (BEE).

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

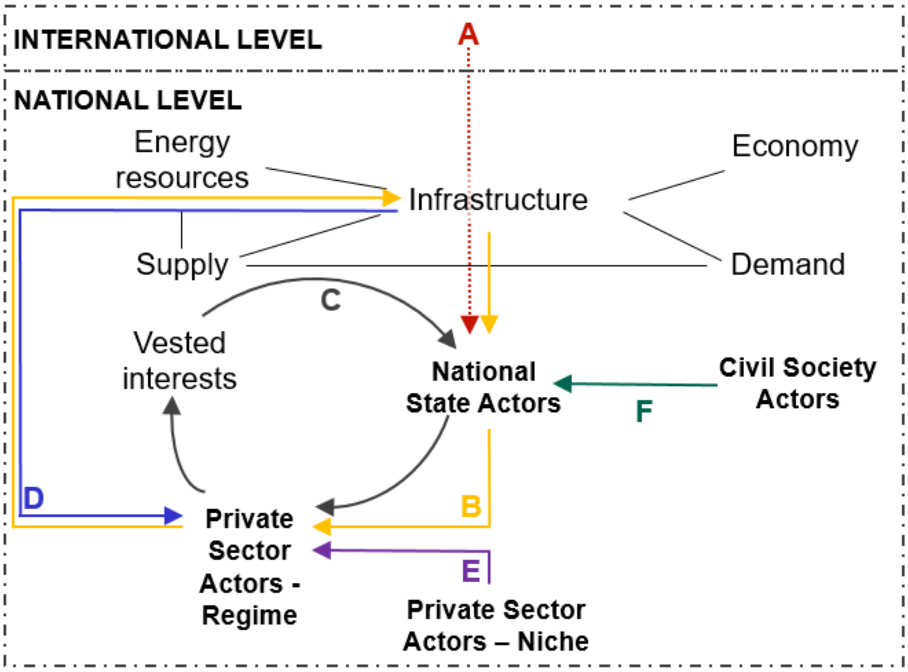

Figure 4-5: Explanatory mechanisms for political support for LNG investments in Germany.

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

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.

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 4.5.2.2), 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 2018; 2019b). Reasons for the increase are, however, not only the political pressure but also various global LNG market developments (see Introduction and Section 4.5.2). 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.[75] 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.[76]

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.

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 4.5.1.1). 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

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

[76] Federal Ministry of Finance. 2020. 'Non Paper Germany Nord Stream 2/U.S. LNG'. https://t1p.de/s7cq.

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"[77]. 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.[78] 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.[79] 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).

The terminals are also financially supported through direct federal state subsidies for LNG terminal construction[80] and through the common task budget "Improvement of the Regional Economic Structure".[81] 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.[82] 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.

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[77] 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. Thilo Rohlfs, Handelsblatt. 2018. 'Warum Deutschlands erstes Flüssiggas-Terminal ein Befreiungsschlag wäre'. https://t1p.de/txb3.

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

[79] Telepolis. 2019. '"Erdgas wird die neue Kohle"'. https://www.heise.de/tp/features/Erdgas-wird-die-neue-Kohle-4398966.html.

[80] Süddeutsche Zeitung. 2020. 'Finanzausschuss stimmt Investitionspaket zu'. https://t1p.de/u4o7.

[81] 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 (Federal Ministry of Finance 2019; 2018).

[82] Telepolis. 2019. '"Erdgas wird die neue Kohle"'. https://www.heise.de/tp/features/Erdgas-wird-die-neue-Kohle-4398966.html.

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 4.5.1.1 and 4.5.1.2).

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[83] 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[84]: 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.

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[85] 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].

[83] Bundesregierung. 2020. ‘Gesetz zur Reduzierung und zur Beendigung der Kohleverstromung und zur Änderung weiterer Gesetze’ (Kohleausstiegsgesetz).

[84] 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).

[85] Yara is one of the five single biggest gas consumers in Germany (0.7 bcm in Brunsbüttel; ~1% of German gas consumption). Boyens Medien. 2028. ‘Gute Ernte: Yara in Brunsbüttel’. https://t1p.de/ftxs.

> *"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[86] [Interview_PSA]. The consulting firm created the "Maritime LNG Plattform e.V." (see Section 4.5.1.2), 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).[87]

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 2019a), 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 technical requirements that would need a different terminal design and substantial reconstructing with high costs (Klebanoff, Pratt, and LaFleur 2017) (see also Section 4.5.3).

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.[88] 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

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[86] In this case especially the Brunsbüttel terminal.

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

[88] CEO, Food and Water Watch and Friends of the Earth Europe. 2019. 'Big Oil and gas buying influence in Brussels'. https://t1p.de/lxnb.

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 4.5.2.2). One relatively small change for distribution grid operators or power plants is to invest in so-called "hydrogen ready" infrastructure.[89] 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). 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) and 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.

[89] 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].

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.

4.7 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 (Eurostat 2020). 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 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.

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

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.

Chapter 5

Natural gas as a barrier to sustainability transitions? A systematic mapping of the risks and challenges related to the use of natural gas*

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**under review at Environmental Research Letters since March 2021.* This is the version of the article before peer review or editing, as submitted by an author to *Environmental Research Letters*. IOP Publishing Ltd is not responsible for any errors or omissions in this version of the manuscript or any version derived from it.

5 Natural gas as a barrier to sustainability transitions? A systematic mapping of the risks and challenges related to the use of natural gas

Abstract

Research has shown that natural gas (NG) has a significant negative impact on the climate. The role of NG in future global energy systems is highly controversial. Due to the greenhouse gas emissions associated with NG and the potential delay of low-carbon technologies, this energy source could represent a barrier rather than a solution to successful sustainability transitions. However, it appears that very little existing research covers NG-related risks. This paper covers a systematic mapping of literature, compiling existing evidence on the potential risks and adverse effects of using NG. Methane emissions in particular pose large climate risks, while the main barriers to sustainability transitions caused by NG include a crowding-out effect of low-carbon technologies, stranded assets, infrastructure lock-in, and behavioural lock-ins. The resulting political challenges include achieving climate mitigation targets, dealing with opposition to NG reduction, and addressing discursive lock-ins. The studies cited here highlight the fact that the potential of NG to reduce greenhouse gases is small, and that climate targets cannot be achieved via NG use in the long term.

Highlights:

- Natural gas poses a barrier to sustainability transitions due to methane emissions and several lock-in mechanisms.
- Long-term climate targets cannot be achieved via natural gas use.
- Little research exists on the potential of natural gas to delay sustainability transition and its societal and political challenges.

Keywords: Natural gas, methane leakages, lock-in, barriers, sustainability transitions

5.1 Introduction

In 2019, more than 4 trillion cubic metres of natural gas (NG) were produced globally – a new all-time high (IEA 2020b). Almost a quarter of the total global primary energy supply is provided by NG (IEA 2020c). Of all fossil fuels, NG use is the most rapidly growing, and has been responsible for about 35% of the growth in global CO_2 emissions since 2009 (Peters et al. 2020). The total climate impact of NG use is largely influenced by the methane emissions emitted over its full life cycle (Alvarez et al. 2012; 2018; Hausfather 2015; Mac Kinnon, Brouwer, and Samuelsen 2018). Globally, NG is mainly used for power and heat generation, in industrial applications, and, to a much smaller extent, in the transport sector (IEA 2019b). Despite NG's already large contribution to global greenhouse gas (GHG) emissions (Peters et al. 2020; Saunois et al. 2020), gas infrastructure, such as NG wells, power plants, and liquefied natural gas (LNG) terminals, continues to expand. According to the Global Gas Report 2019 published by various gas associations,[91] investments in NG infrastructure amounted to approximately USD 360 billion in 2018. Not only is large-scale infrastructure being expanded, but also the use of gas appliances, such as boilers in homes, or cars and trucks fuelled by compressed natural gas (CNG) or LNG.

The question of whether NG use would need to grow or decline in light of efforts to mitigate climate change has been highly contested. One set of commonly used tools for analysing future energy consumption is the family of Integrated Assessment Models (IAMs). Scenario results from different IAMs included in the reports by the Intergovernmental Panel on Climate Change (IPCC) show a wide range of outcomes when it comes to the future role of NG (Joeri Rogelj et al. 2018). In those scenarios that were compatible with a maximum temperature increase of 1.5°C, the median of scenarios showed a reduction in NG primary energy supply. However, study results ranged from almost a complete phase-out to 100% growth between 2020 and 2050. In comparison, the development of future coal use seems to be less controversial, as the scenarios showed a much narrower range of outcomes, all of which demonstrated the need for reduction (Joeri Rogelj et al. 2018).

The role NG could play in the context of climate mitigation is multifaceted and complex, as it requires more than simple quantification and comparison of total emissions (Mac Kinnon, Brouwer, and Samuelsen 2018). Socio-technical transitions[92] are fundamental, multidimensional, long-term changes of socio-technical systems involving a broad range of actors (Markard, Raven, and Truffer 2012; Geels and Schot 2010; Kemp 1994). Such far-reaching changes include different dimensions, such as technological, institutional, economic, and socio-cultural structures. Sustainability transitions are a subset of socio-technical transitions that are associated with sustainability targets and guided by public policies as a response to “grand challenges” such as climate change. Based on a review by Markard et al. (2012), this paper will use the following definition of “sustainability transition”: A sustainability transition comprises far-reaching changes of the institutional, organisational, technical, social, and/or political aspects of existing socio-technical systems, related to more sustainable or climate-friendly modes of production and consumption.

The majority of NG use has not been covered in sustainability transitions research yet, with existing studies focusing mostly on electricity generation (R. G. Newell and Raimi 2014) or coal (Diluiso et al. under review). While a great deal of literature regarding the technical aspects of NG exists (Mac Kinnon, Brouwer, and Samuelsen 2018), as well as research due to geopolitical conflicts around gas supplies in the field of political science (Balmaceda 2018), there seems to be little energy transitions research specifically addressing NG and its use.

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[91] https://media-publications.bcg.com/SNAM-2019-GGR.pdf.

[92] This paper uses the terms “transition” and “transformation” interchangeably. Differences in the meanings of the two terms exist in the literature, e.g. with regard to a stronger focus on societal contributions to change oftentimes used in the transition literature, or bottom-up “transformations” rather than top-down “transitions”; the term “transformation” also sometimes comprises comprehensive social upheavals (Child and Breyer 2017).

NG has been promoted by many institutions as a so-called “bridge” technology, allowing these institutions to present NG as climate-friendly, and be ambiguous about how long and how much NG use is actually supposed to represent the “bridge” (Delborne et al. 2020). This framing enhances the risk that something that was meant to be a temporary solution will become permanent. If NG became entrenched in infrastructures and economies, it could prevent deeper social change towards low-carbon societies (Castán Broto 2018). In socio-technical systems, a tendency exists for technologies to co-evolve – in a mutually beneficial and dependent manner – with industries, policy, and institutional environments. This can create path dependency, which “occurs when interlinkages or self-reinforcing feedbacks between differing components wed a socio-technical system to developing along its current trajectory […]. This can lock-in carbon-intensive technologies and prevent [the] uptake of environmentally superior alternatives” (Trencher et al. 2020, 1). Already, a large global potential of a carbon lock-in has been found for gas-fired power plants (Erickson et al. 2015).

Therefore, the GHG emissions and potential lock-in associated with NG could represent yet another barrier instead of a simple solution to successful sustainable energy transitions (Brauers, Braunger, and Jewell under review). The objective of this paper is to gather existing research on the risks NG might pose for sustainability transitions. This will allow researchers to develop a deeper understanding and systematise existing evidence on the challenges related to NG. Existing reviews and my own research suggest that it is a conceptually young field, so the next step is to conduct a systematic literature mapping and analyse the following research question: What evidence exists in the sustainability transitions literature on the potential risks and adverse effects of using NG?

Previous reviews have focused on the field of sustainability transitions (Markard, Raven, and Truffer 2012; Köhler et al. 2019), but have neglected the role of NG. Another paper has reviewed literature regarding the emissions from power production with NG (Mac Kinnon, Brouwer, and Samuelsen 2018). However, it did not focus on socio-technical transitions and the impacts that NG has on society, but instead put a technologically detailed focus on different ways to burn NG and different power plant types as well as the resulting GHGs and other pollutants. Another review focusing on phase-outs, discontinuation, and decline of specific fuels and technologies did, interestingly, also included no research on NG (Rosenbloom and Rinscheid 2020).

This paper presents a literature mapping, which provides the reader with an overview of what has already been learned about climate, environmental, techno-economical, societal, and political risks and barriers of NG, as well as existing research gaps. Identifying the resulting barriers to sustainability transitions is especially important, as the upcoming transitions will not be initiated by spontaneous technological, market, and demographic forces, but need to be intentionally partly guided and accelerated by governing institutions (Sovacool, Hess, et al. 2020; Murray and Niver 2020). This is particularly the case in what has been called the “second phase” of energy transitions (Markard 2018). This phase describes a state where the transition has accelerated to such an extent that it challenges established technologies, business models, practices, and actors. It is here that an understanding of lock-ins – and how to overcome them – becomes important. The contribution this mapping makes is to clarify the emerging field of the role of NG in more advanced stages of the energy transition, as well as to provide decision-makers with a concise overview of the relevant risks and barriers.

5.2 Methodological approach

The following section introduces the methodology of systematic literature mapping, the literature search approach used in this mapping, the screening process, and eligibility criteria, as well as the coding strategy applied to the data under review.

5.2.1 Systematic mapping

Systematic maps are part of a general systematic evidence synthesis methodology, used to collate, describe, and catalogue existing research evidence (Haddaway et al. 2018). They involve transparent and repeatable processes, and thereby maximise the objectivity and comprehensiveness of the review procedure. The general aim of such a mapping process is to identify both knowledge clusters and gaps. Systematic mapping is particularly appropriate when there is a lack of empirical data to describe the existing literature across a broad subject of interest (James, Randall, and Haddaway 2016; Berger-Tal et al. 2019).

In contrast to a systematic review, a systematic mapping does not attempt to answer a specific question, but simply to describe the state of knowledge concerning a question or topic (James, Randall, and Haddaway 2016), and allows researchers to pose broader, less focused questions (Berger-Tal et al. 2019). Systematic mapping is therefore more appropriate for this research question than a systematic review, because there is no single answer regarding what risks exist vis-à-vis NG use; instead, a whole range of different answers exist depending on the specific context. Moreover, the role of NG in energy transitions is a new emerging field of research that requires a more open approach.

Another advantage is that a systematic mapping approach does not require a critical appraisal. Since the studies included in this mapping came from many different scientific disciplines and show a broad range of methodological and theoretical approaches, no critical appraisal was conducted. A systematic mapping merely results in a description of the available evidence, highlighting implications for policy, research, and/or practice (James, Randall, and Haddaway 2016).

5.2.2 The search for literature

Since research on NG's risks for energy transitions is an emerging field, the search included peer-reviewed papers as well as, e.g. conference proceedings, working papers, and books. The data collection included primary research articles, academic opinion pieces (perspectives), and reviews. Documents such as newspapers, market research reports, industry profiles, product reviews, country reports, and SWOT analyses were excluded. The search was conducted in October 2020 via three available portals, namely the Web of Science Core Collection, Business Source Complete (Business Source Premier), and Proquest (see Table 6-2 for more information on databases). No other web-based search engines or organisations' websites were included, as the general search focused on academic and not grey literature. Grey literature would have been beyond the scope of this analysis not only for reasons of manageability, but also because it would have created an unwanted bias towards grey literature, where NG is much more a focus topic.

To estimate the comprehensiveness of the search, five benchmark articles were used to check the extensiveness of the search terms. I also discussed these terms with three academic experts on energy transitions and NG, as well as a librarian. Only studies in English were included. The search terms used for each database can be found in the Appendix.

The following is an example of the search term (slightly altered depending on the syntax of the database):

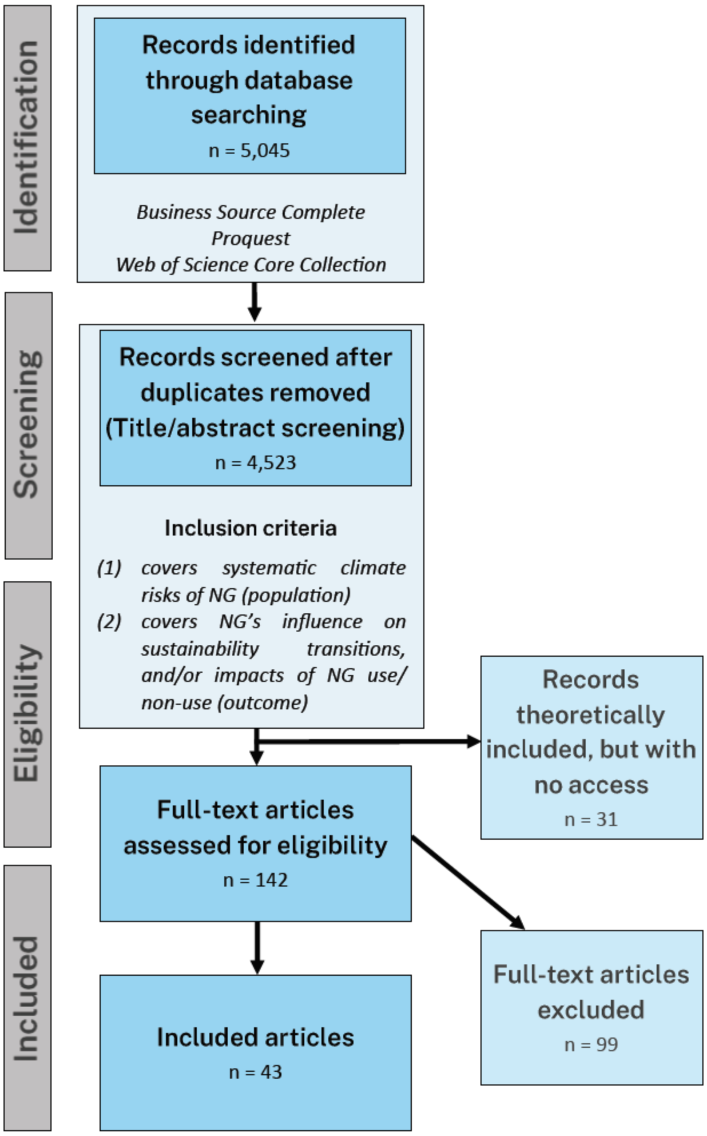
(("fossil gas*") OR ("natural gas*") OR (LNG) OR ("shale gas*") OR (CNG)) **AND** ((transformation*) OR (shift*) OR ("energy transition*") OR ("sustainability transition*") OR ("multi-level perspective") OR ("multi level perspective") OR (MLP) OR ("technological innovation system*") OR (TIS) OR (phase-out*) OR ("phase out*") OR ("phasing out") OR ("phase out*") OR ("sustainability theor*") OR ("socio-technical scenario*") OR ("sociotechnical scenario*") OR ("socio-technical transition*") OR ("sociotechnical transition*") OR ("socio-technical energy transition*") OR ("sustainability transition*") OR ("transition theor*") OR ("energy system transition*") OR ("radical innovation*") OR ("system innovation*") OR ("niche management") OR ("switch*") OR ("transition fuel*") OR ("transitional fuel*") OR ("bridge fuel*") OR ("bridging fuel*") OR ("bridge-fuel*") OR ("bridge techn*") OR ("bridging techn*") OR ("decarboniz*") OR ("decarbonis*") OR ("lock-in*") OR ("locking in") OR ("locking-in") OR ("low-carb*") OR ("zero carbon") OR ("zero-carbon") OR ("climate neutral*") OR ("climate-neutral*") OR ("path depend*") OR ("path-depend*")) NOT (("contracept*"))[93]

The first part of the search string comprises words related to NG: In addition to the main search terms of "natural gas" and "fossil gas", "LNG" and "CNG" were also used, so that these two common forms in which NG can be used and transported were included. Additionally, "shale gas" was also included as a separate term, since the main remaining natural gas reserves can be found in shale fields (see, e.g. Crow et al. (2019)), and remaining unconventional gas reserves have a GHG potential several times higher than conventional gas fields (Broderick and Wood 2014). The second part of the search string relates to aspects of the sustainability transition. It combines terms from the transitions literature (such as from theories, such as the multi-level perspective or technological innovation system), as well as words directly focused on challenges related to NG (such as "lock-in" or "path dependency") and general terms focused on the challenge of climate change (such as "climate-neutral" or "sustainability transitions").

The result was a large corpus of studies that not only focuses on the risks of NG, but also includes literature only discussing the benefits of NG as a so called "bridge" technology. However, it was necessary to include both to get a comprehensive overview of all studies related to NG and the sustainability transition context. The next step was to narrow the corpus down to studies focused on risks, using the application of inclusion and exclusion criteria. The whole approach is summarised in Figure 5-1 and explained in more detail in Section 5.2.3.

[93] "contracept*" was excluded, as otherwise a great deal of literature on contraception methods would have been included in the study collection.

Figure 5-1: Flowchart of the article identification, screening, and selection process.



Source: Author's illustration based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart *(PRISMA 2015)*.

5.2.3 Screening process and eligibility criteria

The screening process was conducted in CADIMA, an open access tool assisting the systematic mapping process (Kohl et al. 2018). The first stage of the screening process consisted of identifying potentially relevant studies via a title and abstract screening. Studies where the title and abstract indicated a different research subject were omitted. To determine which studies were relevant, inclusion criteria were defined. 10% (453) of the papers were screened by the author and one additional researcher to ensure that the inclusion criteria could be applied by different people and still result in the same outcome. We discussed existing discrepancies in coding and refined the inclusion criteria until we achieved the same understanding of the criteria. The final inclusion criteria are the following:

- **Relevant subject:**

(1) Only articles that directly focus on NG will be included and the relevant subject needs to be an energy transition in the context of climate change. The articles not only need to have NG at the centre of their analysis, but need to specifically mention one or several systemic risks related to the climate impact of NG use or production.

(2) A pure analysis of the greenhouse gases related to NG or a life cycle analysis of NG is not sufficient. Articles need to subsequently also discuss NG's relationship to climate mitigation targets or strategies by actors confronted with the decision to use, produce, or regulate NG.

- **Relevant outcomes:** The outcomes are either NG's influence on sustainability transitions or the impacts of NG use or non-use.

Study design, type of intervention(s), and other subject(s) of comparison were not part of the inclusion or exclusion criteria.

After I conducted the remaining 90% of the title and abstract screenings, 173 papers remained for full-text screening. However, 31 of these remaining studies were not available at full-text level, and had to be omitted.

In the second stage, I read and coded the full texts. Studies that failed to include at least one of the inclusion criteria after reading the full text were eliminated. This selection step led to the final amount of 43 included studies.

5.2.4 Data coding strategy

The articles accepted for study were coded using an inductive coding technique, meaning that the papers were first coded based on predefined criteria developed from an initial sample, and then these criteria were re-evaluated and adapted after a full-text reading of 10% of the articles. Therefore, relevant studies were sometimes re-coded once all the categories were developed. The data was collected in an Excel sheet, incorporating the following main categories to collect and interpret the data:

1) *Citation information (year, title, etc.)*
2) *Study basics (type of publication, scientific discipline, journal title, etc.)*
3) *Transition basics (type, scale and period of transition, influence factors, main uncertainties, etc.)*
4) *Climate and environmental risks*
5) *Techno-economic risks*
6) *Social risks*
7) *Political challenges*
8) *Research gaps*

5.3 Mapping the results – descriptive publication statistics and the focus of articles

Despite the results being case-specific, the following mapping aims to distil the more general messages, thus creating an overview of the risks connecting the case studies across sectors and localities.

Most of the 43 articles included in the mapping were written after 2014 (see Figure 5-2). One especially interesting outlier is a study written in 1992, as well as the long gap that occurred until the next study that fitted the mapping criteria was published. Additionally, there is no clear trend of an increasing number of studies after 2015, but rather a new baseline, with a few studies published every year. Of all study authors, around 30% were women. The main institution of 35% of the authors was in the US, 26% in the UK, and 14% in the Netherlands.[94]

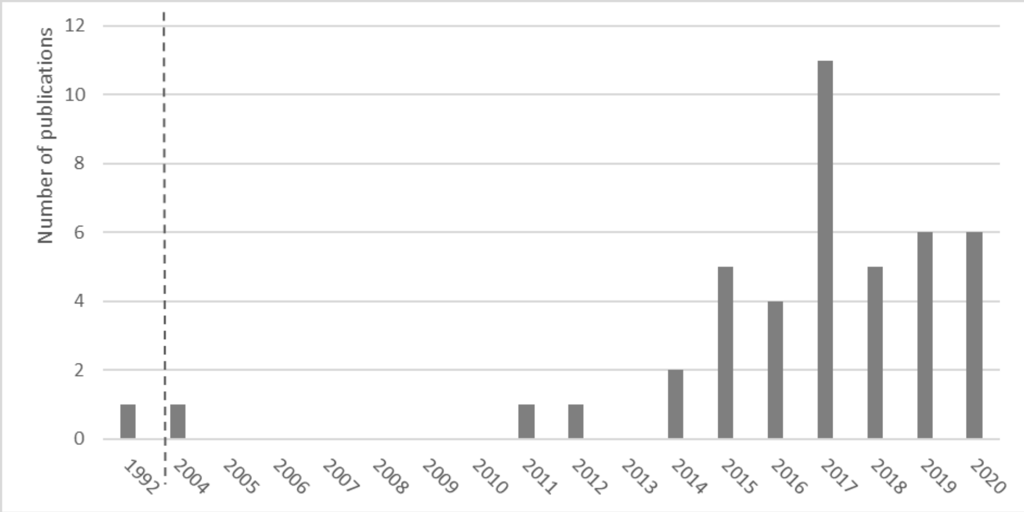


Figure 5-2: Number of publications over time.

The articles have a clear regional focus: 12 case studies analysed the US, nine the UK, and six the Netherlands, while another six articles had a global focus (see Figure 5-3).

Figure 5-3: Geographic location of case studies.

Source: Author's illustration, basic world map from d-maps.[95]

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[94] Canada and Germany 5% (two studies), and Australia, China, Switzerland, Austria, Denmark, Portugal, and Russia 2% (one study each).

[95] d-maps. 2021. "Map World". D-Maps.Com Free Maps. 2021. https://d-maps.com/carte.php?num_car=13181&lang=en.

Figure 5-4 depicts a citation network: Interestingly, the majority of studies are actually not connected to each other. The only study cited by a larger number of studies is Shearer et al. (2014). One reason seems to be that the studies come from different scientific disciplines, and apply different methods. Twenty-five studies (more than 50% of the articles included) did not cite or were not cited by any of the others. The main journal where studies were published was Energy Policy (10 articles; see Table 6-3 in the Appendix). 53% of the studies used quantitative methods, 30% qualitative, and 16% mixed methods.[96]

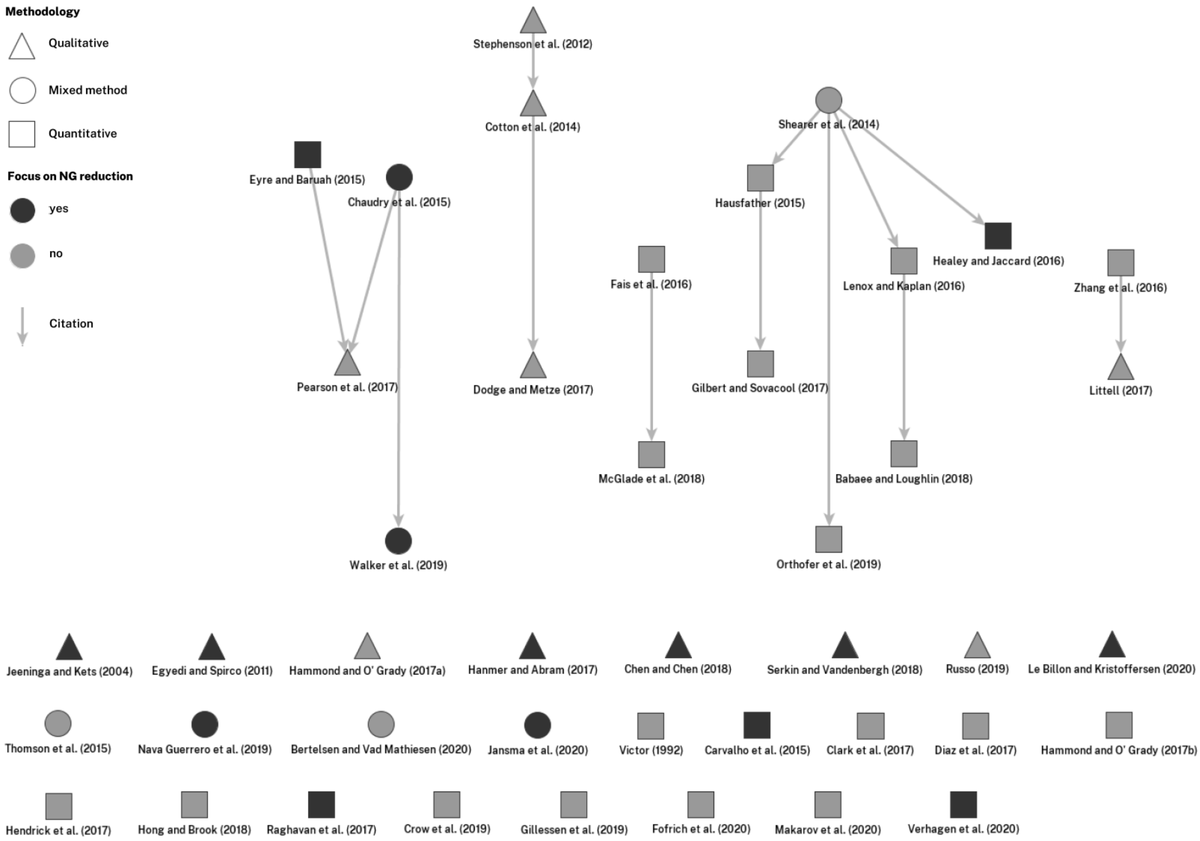


Figure 5-4: Citation network – all studies.

In addition to the lack of links between papers, the limited citation of articles included in the mapping is also noteworthy. Table 5-1 shows the citation count of all studies that were cited at least 10 times according to the Web of Science Core Collection. Two studies dominate the citation count with 98 and 80 citations respectively; all other studies show quite low citation counts (some of them being zero), and even the article with the most interconnections in this mapping has only 34 citations in total. This can be interpreted in the following way: Not only is there not yet a field targeting the risks of NG and how to

[96] This does not add up to 100% due to rounding effects. Quantitative methods included, e.g. energy system models such as TIMES or MARKAL, and input-output models; qualitative methods included, e.g. actor network theory and argumentative discourse analysis; one mixed-method example was a combination of quantitative multi-objective simulations with qualitative feasibility assessments.

mitigate them, but even the existing research has so far received very little attention by the transition field and academia in general.

Table 5-1: Studies included in the mapping and their citation count >10.

Year	Authors	Title	Times cited
2014	Cotton et al.	Shale gas policy in the United Kingdom: An argumentative discourse analysis	98
2015	Thomson et al.	Natural gas as a marine fuel	80
2016	Zhang et al.	Climate benefits of natural gas as a bridge fuel and potential delay of near-zero energy systems	48
2012	Stephenson et al.	Greenwashing gas: Might a 'transition fuel' label legitimize carbon-intensive natural gas development?	40
2014	Shearer et al.	The effect of natural gas supply on US renewable energy and CO_2 emissions	34
2015	Chaudry et al.	Uncertainties in decarbonising heat in the UK	32
2015	Eyre et al.	Uncertainties in future energy demand in UK residential heating	31
2015	Hausfather	Bounding the climate viability of natural gas as a bridge fuel to displace coal	27
2015	Carvalho et al.	Ground source heat pump carbon emissions and primary energy reduction potential for heating in buildings in Europe – results of a case study in Portugal	22
2016	Fais et al.	Impact of technology uncertainty on future low-carbon pathways in the UK	22
2018	McGlade et al.	The future role of natural gas in the UK: A bridge to nowhere?	20
2016	Lenox and Kaplan	Role of natural gas in meeting an electric sector emissions reduction strategy and effects on greenhouse gas emissions	16
2017	Gilbert and Sovacool	Benchmarking natural gas and coal-fired electricity generation in the United States	14
2011	Egyedi and Spirco	Standards in transitions: Catalyzing infrastructure change	13
2018	Hong and Brook	A nuclear-to-gas transition in South Korea: Is it environmentally friendly or economically viable?	12
2017	Diaz et al.	Do We Need Gas as a Bridging Fuel? A Case Study of the Electricity System of Switzerland	10
2020	Le Billon and Kristoffersen	Just cuts for fossil fuels? Supply-side carbon constraints and energy transition	10

Note: The citation count is from the Web of Science Core Collection as of January 2021. Since several studies included in the mapping were published in 2020 (or earlier), the citation count could still change substantially.

The majority of the articles focus on the national level (32), while three articles focus on the subnational level, two on the regional, one on the city level, and six consist of a global analysis.[97] Three articles could be counted as opinion pieces rather than research articles, but were nevertheless included because they were published in academic journals: Russo (2019), Littell (2017), and Serkin and Vandenbergh (2018).

Since the mapping covers NG in the context of *sustainability* transitions, the articles' treatment of climate mitigation was of particular interest. The articles referred to very different GHG emission reduction targets; however, most referred to the Paris 2°C target or a -80% GHG reduction by 2050 (compared to

[97] Note: This does not add up to 43 because one study looks at two different levels.

1990 levels) in the respective locality (24 out of the 43 studies). Despite the focus on NG's climate impact, only about 50% of the studies covered both the CO_2 and methane emissions of NG directly.

Interestingly, 20 articles started with the assumption that NG use or production needs to be reduced to achieve sufficient levels of climate change mitigation, and then analysed ways to achieve such a reduction. The other 23 articles partly analysed whether NG actually poses a risk for sustainability transitions. Only 15 articles analyse specifically *how* to reduce NG use and/or production.

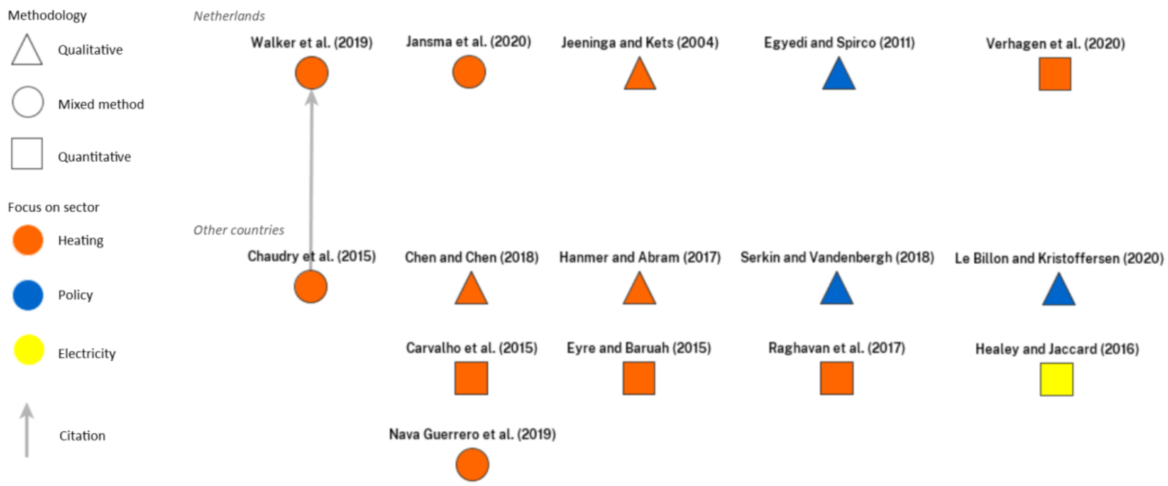


Figure 5-5: Citation network – studies that focused on how to reduce NG production or consumption.

The citation network is even more revealing when it comes to the articles that focused on *how* to reduce NG production or consumption to mitigate climate risks (see Figure 5-5): There is only one citation link. All the other studies do not refer to each other, despite the fact that the topics overlap to a significant degree: One focus is heating in general, and the other heating in the Netherlands in particular. No methodological focus can be observed. It is likely that the electricity sector is covered through a distinct type of articles, where the focus is on the shift *towards renewables*, and not on the *reduction of natural gas*, which would explain why they do not appear in the mapping. Heating however, might be approached from the other side – focusing on the aspect of how to reduce NG.

At least as interesting as what these papers cover is everything that has not yet been covered. The citation network shows a clear lack of research on the main sectors using NG – transport and industry – as well as on other social and political challenges in the energy sector, such as how to overcome lock-ins, incumbency, or imbalances in actor power, that affect plans for the managed reduction of NG use.

Interestingly, three papers also have a policy focus: Egyedi and Spirco (2011) investigated what role standards could play in facilitating the reduction of NG through a different use of the network; Le Billon and Kristoffersen (2019) conducted a more general analysis about the role that supply-side policies could play in reducing NG and other fossil fuel production, and Serkin and Vandenbergh (2018) explored their proposal of prospective grandfathering.[98] Another article focused on reducing NG in electricity generation, and especially the influence that low NG prices and climate policies can have (Healey and Jaccard 2016).

What this exploratory work shows is a lack of focus on NG in transitions literature, so that knowledge on *how* to reduce NG consumption and production in the context of sustainability transitions aiming to achieve climate mitigation can be developed. All types of articles included in the systematic mapping show that a lot can be learned about the risks to the climate from NG production and consumption; this is the focus of the subsequent sections. The risks are divided into climate and environmental risks (Section 5.4.1), techno-economic risks (Section 5.4.2), and social risks (Section 5.4.3), as well as the resulting political challenges (Section 5.5).

5.4 Mapping the results – risks related to natural gas use and production

5.4.1 Climate and environmental risks

5.4.1.1 Overall GHG impact and methane leakages

Articles included in the mapping highlight the overall carbon footprint from NG use. Carbon dioxide is emitted not only when NG is burned, but also arises from flared gas or from venting of the waste CO_2 content in raw gas (Crow et al. 2019). However, the most important contribution of NG to climate change is methane – which is simultaneously the source of the most uncertainty and the most controversy.

Methane is one of the main GHGs accelerating climate change. Methane emissions related to NG production and use occur during operational and intermittent vents, fugitive emissions, and incomplete NG combustion (Crow et al. 2019). Several of the articles highlighted fugitive emissions of NG as a major GHG risk (Cotton, Rattle, and Van Alstine 2014; Hammond and O'Grady 2017a; Shearer et al. 2014; McGlade et al. 2018; Thomson, Corbett, and Winebrake 2015; Victor 1992; Babaee and Loughlin 2018). Estimates of global methane emission leakage from NG systems could amount to 5% of the total produced gas (Hendrick, Cleveland, and Phillips 2017). According to different studies, methane leakage rates range from 2.3% to 17% (Lenox and Kaplan 2016). The substantial variation of these rates depends on the calculation method (bottom-up or top-down calculations, with data often provided by the industry itself or atmospheric data). This is crucial, because the assumed methane leakage rates in studies often determine whether the model indicates if NG use leads to a slight increase or a slight decrease in total system GHG emissions (Zhang et al. 2016; Shearer et al. 2014; Lenox and Kaplan 2016).

Since most leakages arise upstream (during production and transport), a large gap exists between direct GHG emissions from burning NG and total system emissions. As electricity or heating systems become

[98] Prospective grandfathering aims to enable the use of NG now, while at the same time already setting legal boundaries for the phase-out of NG to prevent litigation and therefore a likely slowdown of the reduction in NG consumption in the future.

increasingly decarbonised and/or become more efficient, upstream NG emissions could account for even larger percentages of total emissions (Hammond and O'Grady 2017b). However, calculations made on a political level usually only include domestic emissions or even only sector emissions, leaving a large share of total emissions unaccounted for and unregulated.

The total calculated climate impact (comparing, e.g. NG with coal) depends closely on the choice of time horizon (typically 20, 100, or 500 years) and the climate change metric used. Common metrics include, e.g. the global warming potential (GWP), mean radiative forcing, or mean temperature change. Metrics that focus on shorter time scales tend to place more emphasis on low methane leakage rates, while those that emphasise longer time scales tend to stress the efficient usage of fuels (Zhang et al. 2016). Scenario calculations with a high NG resource use often result in an increase in GHG emissions, especially when the model uses a 20-year time frame for the GWP and assumes higher upstream methane emissions (Lenox and Kaplan 2016).

The time period considered might have a stronger impact than the choice of metric on whether NG can be a GHG-reducing intermediate fuel. Under various combinations of time period, metric, and methane leakage rate, NG could result in short-term CO_2 emission reductions, and nevertheless result in additional short-term warming (Zhang et al. 2016). In addition, calculating the climate impact of NG is a challenge due to large uncertainties regarding the mean residence time of methane in the atmosphere, as well as the strength of the OH feedback[99] and radiative feedbacks[100] (Victor 1992).

When going from these more abstract GHG impacts of NG to specific applications, aging infrastructure is particularly vulnerable to leakage (Hendrick, Cleveland, and Phillips 2017). The GHG emissions intensity of NG **production** is greatly affected by the ultimate recovery – the volume of gas actually produced by a well (Stephenson, Doukas, and Shaw 2012). Although methane leaks correlate with the age of wells and their production rates, the main drivers of emissions are related to maintenance and/or the specifics of production at a particular location (Crow et al. 2019). In the **power sector**, NG is often analysed as a potential replacement for existing coal-fired power plants. However, the question of whether NG reduces GHG emissions compared to coal depends on several factors, including the methane leakage rate, the emissions efficiency of the replaced power plant, and the type (and hence efficiency) of natural gas plant, as well as the timeframe under consideration (Gilbert and Sovacool 2017). One potential risk is that a coal-to-gas switch can (under certain conditions) reduce GHG emissions in the short term, yet make deeper emission reductions at a later stage more challenging (Healey and Jaccard 2016) (see Sections 5.4.2.3 and 5.5.2). Even Carbon Capture and Storage (CCS) deployment was shown to be sensitive to methane leakage rates: Interestingly, high methane leakage

[99] One major influence on atmospheric methane concentrations is the methane removal rate: Most significantly, its reaction with the hydroxyl radical (OH) balances methane emissions. Methane levels are directly impacted by variations in the oxidation capacity of the atmosphere (primarily by OH). Methane emissions thereby extend the lifetime of methane in the atmosphere and lead to further increases in methane concentration (Dean et al. 2018; Victor 1992).

[100] "[T]he oxidation of methane also increases tropospheric ozone concentrations, which increases greenhouse forcing since ozone is a greenhouse gas. […] [Additionally,] methane contributes to stratospheric water vapor and increases greenhouse forcing since water vapor is also a greenhouse gas" (Victor 1992, 129).

rates changed the scenario results from deploying gas-fired power plants with CCS towards renewables and coal-fired plants with CCS (Babaee and Loughlin 2018).

For **residential heating**, NG use does not necessarily imply a comparatively low GHG impact. In the EU, for example, for six out of the eight member states primarily using NG for heating (the Netherlands, the UK, Slovakia, Luxembourg, Belgium, and Germany), the average CO_2 emissions from residential heating are higher than the EU-28 average (Bertelsen and Vad Mathiesen 2020). Increased NG use for **marine fuels** could also increase global GHG emissions when upstream emissions are considered (Thomson, Corbett, and Winebrake 2015).

Hence, the aspects raised in the articles allude to the fact that climate targets may not be met due to NG-related GHG emissions.

5.4.1.2 Other environmental risks

Most of the other environmental risks surrounding NG mentioned in the articles are related to water. Specifically, chemicals used for hydraulic fracturing (fracking) and NG production more generally can pollute both air and (drinking) water – and thereby also pose a risk for human health (Cotton, Rattle, and Van Alstine 2014; Stephenson, Doukas, and Shaw 2012; Dodge and Metze 2017; Orthofer, Huppmann, and Krey 2019; Hammond and O’Grady 2017b). Large quantities of water are not only required for NG production, but also for NG power plants, which increase even further when CCS technologies are installed (Babaee and Loughlin 2018). In addition to water contamination, water-scarce countries in particular are at risk from lower water table levels and increased water demand by the NG industry (Orthofer, Huppmann, and Krey 2019). “[E]cosystem degradation and adverse effects on aquatic habitats, erosion, and changes in water temperature” (Hammond and O’Grady 2017a, 1911) are other potential consequences of fracking.

Other environmental risks mentioned were seismic activity (earthquakes) (Cotton, Rattle, and Van Alstine 2014; Dodge and Metze 2017; Hammond and O’Grady 2017a), noise (Hammond and O’Grady 2017a), light pollution (Cotton, Rattle, and Van Alstine 2014), and landscape-scale impacts of shale gas infrastructure, such as habitat fragmentation and degradation (Stephenson, Doukas, and Shaw 2012) and traffic congestion (Cotton, Rattle, and Van Alstine 2014). In general, the natural gas industry was referred to as proliferating industrial landscapes (Dodge and Metze 2017; Orthofer, Huppmann, and Krey 2019).

5.4.2 Techno-economic risks

The techno-economic risks can be grouped into the following sub-groups: The crowding-out of low-carbon technologies, financial risks, infrastructure lock-in, risks related to carbon capture, and otherwise unclassified techno-economic risks.

5.4.2.1 Crowding-out of low-carbon technologies

A major risk of additional investment in NG and low-cost NG is that such investment could delay and impede the rate of deployment of low-carbon sources of energy or energy-demand reduction measures (Stephenson, Doukas, and Shaw 2012; Hammond and O’Grady 2017b; Cotton, Rattle, and Van Alstine

2014; Chen and Chen 2019; Lenox and Kaplan 2016; Healey and Jaccard 2016; Littell 2017; Orthofer, Huppmann, and Krey 2019; Zhang et al. 2016; Hammond and O'Grady 2017a; Shearer et al. 2014; Hausfather 2015; McGlade et al. 2018). This can happen via three distinct mechanisms:

(1) (Over-)investments in NG directly substitute investments that would otherwise have been made in low-carbon technologies;
(2) An inexpensive supply of NG decreases energy prices and further delays the point in time when low-carbon technologies become competitive;
(3) Delaying investment in low-carbon technologies postpones learning curves, and costs of low-carbon technologies therefore increase.

5.4.2.2 Financial risks

Despite the fact that NG is often highlighted as a cheap solution, large financial risks in the context of sustainability transitions exist: The main risk is the *stranded asset risk* of, for example, power plants, production facilities, transport infrastructure, or gas storage (Fofrich et al. 2020; Zhang et al. 2016; Serkin and Vandenbergh 2018; McGlade et al. 2018; Stephenson, Doukas, and Shaw 2012; Russo 2019; Crow et al. 2019; Gillessen et al. 2019; Healey and Jaccard 2016). As Section 5.4.2.3 below notes, the prospect of stranded assets would make it attractive to continue to use NG, which would in turn result in greater climate impacts (Díaz, Vliet, and Patt 2017).

When climate goals are adhered to, studies found that the continued use of NG delivers no overall cost savings, and could even increase cumulative transition costs (Díaz, Vliet, and Patt 2017; Nava Guerrero et al. 2019). As an example, gas-fired power plants would only be able to run at very low load factors (McGlade et al. 2018), often rendering the business unattractive for investors and operators. Therefore, considerably reducing NG use would have major implications for the energy sector and its companies along the entire value chain. Jobs would change not only upstream in production and in large power plants, but also for gas fitters installing appliances in homes, for example (Eyre and Baruah 2015).

5.4.2.3 Infrastructure lock-in

Another risk category is path-dependent infrastructure: The building of new NG infrastructure generally carries with it the risk that an area will then be locked into this emission-intensive energy infrastructure (Stephenson, Doukas, and Shaw 2012; Hammond and O'Grady 2017a; Serkin and Vandenbergh 2018; McGlade et al. 2018). Infrastructure systems for producing and using NG typically have a functional lifetime of several decades. Once the infrastructure exists, it is more likely that GHG emissions will increase and that GHG targets will be neglected, due to the resulting economic and political pressure, for example (Hammond and O'Grady 2017b; Eyre and Baruah 2015; Serkin and Vandenbergh 2018; Verhagen, der Voet, and Sprecher 2020).

Existing infrastructures are difficult to change (Egyedi and Spirco 2011; Hanmer and Abram 2017; Thomson, Corbett, and Winebrake 2015). Path-dependency effects arise due to increasing returns of scale, and sunk costs contribute to a lock-in effect of incumbent technological choices. Technological network effects are also important sources of path-dependency, as the supply chain elements must be compatible with the overall system (Bertelsen and Vad Mathiesen 2020). Taking an example from the heating sector, individual boilers are fuel-specific and cannot easily be repurposed to use other fuels

(Bertelsen and Vad Mathiesen 2020), which would result in high costs if alternative heating options were to be introduced (Hanmer and Abram 2017).

5.4.2.4 Risks related to carbon capture

Using NG in the absence of CCS might compromise the path to decarbonisation (Pearson and Arapostathis 2017; Hammond and O'Grady 2017a; Babaee and Loughlin 2018). If CCS does not become available as a large-scale technology, NG will need to be greatly reduced and then phased out (Pearson and Arapostathis 2017; Hammond and O'Grady 2017b; Fais et al. 2016; McGlade et al. 2018). In scenario analyses, the non-availability of CCS had the strongest negative impact on NG use (Fais et al. 2016).

Even when CCS is available, NG plants combined with CCS (NG-CCS) would only create significant climate benefits if methane leakage rates are minimised (Gilbert and Sovacool 2017). The deployment of NG-CCS is expected to depend on the cost and performance of CCS, as well as broader contextual factors (Babaee and Loughlin 2018). Deploying CCS in the power sector would add an extra cost to electricity generation and reduce overall efficiency (Babaee and Loughlin 2018; Hammond and O'Grady 2017a). In addition, due to the low CO_2 concentrations of NG-CCS, the cost-effectiveness of capture technologies is low (Babaee and Loughlin 2018). Overall, focusing mainly on NG-CCS would "constitute a significant risk of climate change policy failure" (Hammond and O'Grady 2017a, 1912). Due to the high risk that CCS poses for climate change, it has been characterised as "a last-ditch effort at best" (Serkin and Vandenbergh 2018, 1048).[101]

5.4.2.5 Other techno-economic risks

In addition to all the previously mentioned risks, the use of NG can pose other technological risks. For example, the actual flexibility of a NG power plant – often presented as one if its main strengths – can be constrained by the upstream gas supply and its transport. If gas is not delivered in time, a gas turbine is neither flexible nor reliable. The flexibility of a NG power plant varies widely, in part due to thresholds regarding minimum stable load, the time a plant needs to restart after a shutdown, and decreased longevity as a result of multiple stop-start cycles (Littell 2017).

More generally, it has been argued that sector-wide contributions to GHG emission abatement is highly sensitive to technology failure (Fais et al. 2016). Allowing longer power plant lifetimes would require even larger negative emissions than the "prodigious quantities" already assumed (sometimes many Gt CO_2 per year) (Fofrich et al. 2020, 8). NG consumption and infrastructure use also depends on the development of other technologies, such as bio-methane, synthetic gases, or the resource potential of bioenergy (Hammond and O'Grady 2017b).

[101] In addition to NG-CCS, biogas combined with CCS has also been analysed: "From a risk perspective, the reliance on bio-CCS in some scenarios is interesting as it combines the unproved CCS with a resource with uncertain availability" (Fais et al. 2016).

More generally, rebound effects might increase the challenge NG poses for transitions. For countries that also produce NG for their domestic consumption, declining production that was to be replaced by gas imports would actually mostly lead to GHG emission increases, as additional transport-related emissions would occur (due to fugitive emissions on long transport routes as well as energy-intensive processes such as liquefaction) (Hammond and O'Grady 2017b; 2017a). Another example of a rebound effect is the shale gas boom in the US, which lowered domestic NG prices and subsequently led to a decrease in coal use in the US, which itself in turn might lead to increasing exports of cheap coal to other parts of the world (Cotton, Rattle, and Van Alstine 2014).

5.4.3 Social risks

The main social risks can be categorised in health, institutional path-dependency, knowledge, discursive lock-ins, and governance challenges related to those social risks. Some of these social risks were implicitly covered in climate and other environmental risks, posing dangers for the health and safety of civil society.

5.4.3.1 Health

As alluded to in Section 5.4.1.2, producing NG can contaminate air and drinking water, creating negative health impacts for citizens close to production sites (Stephenson, Doukas, and Shaw 2012; Cotton, Rattle, and Van Alstine 2014). The articles in the mapping named gas-related accidents (Hong and Brook 2018) and the threat of earthquakes (Cotton, Rattle, and Van Alstine 2014) as additional threats. Studies also identified an increased human mortality rate due to shale gas (compared to conventional gas, nuclear, or renewables) (Hammond and O'Grady 2017a).

Some risks, especially invisible ones (such as GHG emissions, or risks that occur underground such as the contamination of aquifers or seismic activity), are beyond the direct perception of lay people. Moreover, those risks are spatially diffuse, uncertainty exists about which region will be affected to what extent, and the effects are often temporally delayed (Cotton, Rattle, and Van Alstine 2014).

5.4.3.2 Behavioural lock-in

The speed of necessary major changes in practice are a challenge (Eyre and Baruah 2015) for sustainability transitions reducing NG use, as behavioural lock-in could prevent changes where NG use is already prevalent. The following section uses the heating sector on a building level as a heuristic of behavioural lock-in, where it arises mainly due to three reasons:

(1) **Familiarity and satisfaction**: Relatively high current satisfaction levels with gas-fired heating exist among owners as well as tenants who currently use it (Pearson and Arapostathis 2017; Jansma, Gosselt, and de Jong 2020).

(2) **Negative financial consequences:** Due to the related infrastructure lock-in, a long series of events and relationships needs to occur for a new heating system to emerge (Hanmer and Abram 2017). Investment costs in an alternative heating system would be higher than NG heating due to the frequent need to invest not only in the heating technology itself, but also in the insulation of houses and additional supplementary infrastructure (Chaudry et al.

2015; Hanmer and Abram 2017). Therefore, a change would often have negative financial consequences and hence potentially negative social consequences as well (Jansma, Gosselt, and de Jong 2020; Verhagen, der Voet, and Sprecher 2020).

(3) **The knowledge gap:** Research on the Netherlands has also shown that, despite being aware that the government intends to disconnect all households from NG, the public has little knowledge about the national transition policies concerning sustainable heating and the respective plans for their neighbourhood. Participants of the study also knew little about possible alternatives to natural gas (Jansma, Gosselt, and de Jong 2020), which was similar to findings for the UK (Chaudry et al. 2015).

"It will require an adaptive flexibility that households have tended not to demonstrate except in wartime" (Pearson and Arapostathis 2017, 492), which, however, governments will need to harness if they hope to follow through with a successful sustainability transition.

5.5 Mapping results – political challenges

5.5.1 Achieving climate targets

The main political challenge is that increasing the use of NG cannot deliver sufficient emission reductions for existing climate change targets (Hammond and O'Grady 2017b; Russo 2019; Hammond and O'Grady 2017a; Serkin and Vandenbergh 2018; Shearer et al. 2014; Verhagen, der Voet, and Sprecher 2020; Jeeninga and Kets 2004; McGlade et al. 2018; Healey and Jaccard 2016). There is actually a risk of failing to achieve GHG emission reduction targets because of NG use (Carvalho, Mendrinos, and De Almeida 2015; McGlade et al. 2018; Verhagen, der Voet, and Sprecher 2020; Healey and Jaccard 2016; Hammond and O'Grady 2017a). Even the limited potential for GHG emission reductions "could be eroded if the expanded natural gas deployment delays introduction of near zero emission energy systems" (Zhang et al. 2016, 321). Continued investments in natural gas infrastructure are a particular challenge for more ambitious climate mitigation scenarios, with newly commissioned projects creating the greatest inertia and GHG overshoot (Fofrich et al. 2020; Littell 2017). Doubts exist whether current energy and climate policy strategies can achieve climate targets, and whether a failure to do so could lead to a relaxation of the targets instead of a change in strategies (Pearson and Arapostathis 2017; Eyre and Baruah 2015).

Deregulatory efforts regarding emissions today will only increase the necessary speed and depth of transition away from natural gas in later eras (Serkin and Vandenbergh 2018). Moreover, investing too much in a single strategy (such as a coal-to-gas transition) risks long-term lock-in that would exceed climate targets (Littell 2017). One tool that governments can apply to regulate NG production and use is putting a price on GHG emissions. Several studies mentioned the important effect that, e.g. carbon pricing, can have on steering the level of NG use (Orthofer, Huppmann, and Krey 2019; Chaudry et al. 2015; Crow et al. 2019; Fais et al. 2016; Healey and Jaccard 2016; McGlade et al. 2018; Verhagen, der Voet, and Sprecher 2020; Serkin and Vandenbergh 2018; Shearer et al. 2014; Jeeninga and Kets 2004; Díaz, Vliet, and Patt 2017). However, a related governance challenge is to achieve political feasibility:

Overly low prices would have no impact, while overly high carbon prices might cause opposition by the NG industry and have other negative social consequences.

5.5.2 Overcoming institutional lock-ins

Path dependency arises not only from physical infrastructure, but also from institutional and regulatory contexts. Large technical systems such as an energy system (partly) based on natural gas – be it for the electricity, heating, transport, or industry sector – create interdependencies, which further complicate change (Egyedi and Spirco 2011). The heating sector can again be taken as an example that demonstrates how challenging it is to design a transition plan and implement such changes (Nava Guerrero et al. 2019). As markets and institutions become more intertwined and irreversible over time, they create institutional path dependencies. The institutions associated with an NG-based heating system are aligned in a strong and stable system. A great deal of effort and expense is required to change such a network (for example, by changing to lower-carbon options). Insofar as social, legislative, political, and economic institutions need to align around new institutions, the failure of just one dimension can impede the entire development (Hanmer and Abram 2017).

5.5.3 Balancing the energy policy trilemma

A recurring theme related to NG is the *energy policy trilemma* – providing sustainable, affordable, and secure energy. Since these three objectives sometimes conflict, this has proven to be difficult for governments to achieve (Orthofer, Huppmann, and Krey 2019; Pearson and Arapostathis 2017). Energy security is a particularly important goal of governments (Eyre and Baruah 2015). The diversification of gas supplies, for example, has therefore played an important role for NG-importing countries. In the EU, the declining capacities of the UK's and Norwegian continental shelves, as well as the reduction of Dutch NG production have begun to raise concerns among many member states (Pearson and Arapostathis 2017; Carvalho, Mendrinos, and De Almeida 2015; Hammond and O'Grady 2017a). Energy security concerns tend to be even larger where NG demand is still growing. Cities with rapid population growth and areas experiencing a general trend of urbanisation especially might perceive insufficient gas supply as a threat (Chen and Chen 2019).

Governments often prioritise economic growth over the need to address potentially negative climate change impacts. The "affordability" part of the energy trilemma also frequently trumps other sustainability concerns such as health, air, and water quality (Cotton, Rattle, and Van Alstine 2014). Generally, supply concerns are, however, starting to shift from "peak supply" concerns (not having enough supplies) to "stranded assets" (having more resources than should be consumed in line with climate targets) (Le Billon and Kristoffersen 2019).

5.5.4 Handling opposition to a reduction in NG

The natural gas industry will likely object to and try to resist any regulatory efforts (Serkin and Vandenbergh 2018), as it remains a powerful lobbyist for its own interests (Hendrick, Cleveland, and Phillips 2017). This is especially the case in countries where NG-related revenues constitute an important share of the economy and government revenues (Le Billon and Kristoffersen 2019).

Resistance is likely when change is expected to upend existing markets and dominant technology regimes (Egyedi and Spirco 2011). Overcoming lobbying efforts by investors fearing stranded assets is a main political challenge. In the past, climate policies have violated existing property rights of companies – resulting in compensation payments. This in turn has created doubts among policymakers regarding strict regulations, hoping to avoid litigation (Serkin and Vandenbergh 2018). One example of industry opposition concerns the regulation of methane emissions – despite growing evidence that this might prevent "superemitter" leaks and reduce emissions generally (Hendrick, Cleveland, and Phillips 2017).

GHG emitters such as NG producers or infrastructure operators have appeared to doubt government commitments to climate policy targets, because industry representatives have assumed the political will to be lacking, or that the targets would be impossible to achieve at a reasonable social cost. This can lead to a presumption of zero or very low carbon prices, resulting in investment decisions that are incompatible with ambitious climate policies (Healey and Jaccard 2016). However, if those climate targets are adhered to, "decommissioning trillions of dollars' worth of privately-owned capital after only ~25% of its anticipated life has elapsed will present enormous political […] challenges" (Fofrich et al. 2020, 8).

Ambitiously enforced climate policy would likely lead to a reduced demand for natural gas. This in turn would lead to a decrease in revenues for gas-exporting countries, which could experience negative GDP and welfare impacts (Makarov, Chen, and Paltsev 2020). The degree of the impact, and therefore also the appropriate policy tool, depends on the overall production of NG, the share of GDP that gas rents produce, and whether NG is also consumed domestically (Le Billon and Kristoffersen 2019). In general, one governance challenge lies in the appropriate timing of the transition to alternative technologies, balancing total costs and carbon savings (Raghavan, Wei, and Kammen 2017).

5.5.5 Determining the right level of financial support

Since the advantages of switching from NG to low-carbon alternatives do not directly benefit consumers or NG industry actors, but instead arise by reducing negative externalities in the system (Hanmer and Abram 2017), it is more challenging for governments to create support for the transition (Pearson and Arapostathis 2017). With current energy prices and taxes, the return on investment for all alternative low-carbon heating technologies over several decades has been generally negative.[102] Therefore, government intervention is needed to improve the deployment of technologies consistent with a sustainable energy transition (Verhagen, der Voet, and Sprecher 2020). Simply mandating existing retrofits and the replacement of appliances (Raghavan, Wei, and Kammen 2017) or merely increasing the price of NG would make the cost of urban heating more (and potentially prohibitively) expensive. Hence, additional subsidies for existing buildings and homeowners are needed (Verhagen, der Voet, and Sprecher 2020).

[102] The exact amount is always specific to the case study.

In the Netherlands, where a heating transition away from gas has already been announced at the national level, local governments have struggled to engage citizens in the transition. The mandated drastic changes to buildings alone have posed a barrier for homeowners or tenants in terms of costs and disruption (Hanmer and Abram 2017; Verhagen, der Voet, and Sprecher 2020; Jansma, Gosselt, and de Jong 2020). The subsidies allocated so far only cover part of the costs that housing owners will need to pay for the installation of new technology and improved insulation (Jansma, Gosselt, and de Jong 2020). Many citizens also still see heat pumps or district heating as undesirable (Chaudry et al. 2015; Jansma, Gosselt, and de Jong 2020).

Turning to the power sector, new policy instruments will also be needed, for example to manage the decline of NG-fired power generation: They will need to keep sufficient capacity online in the interim, while at the same time drastically reducing full-load hours (McGlade et al. 2018). Whether a coal-to-gas switch is beneficial needs to be carefully analysed comparing short-term and long-term benefits as well as the costs of abundant gas (Healey and Jaccard 2016). What is interesting in this context is again how few articles included in this study provided those careful analyses, showing that current academic literature has surprisingly little to offer as guidance for decision-making concerning natural gas.

5.5.6 Managing missing data and standards

One hurdle for governments when regulating the NG sector is the lack of emission data, which restricts the governments' capacities to evaluate potential costs and benefits (Stephenson, Doukas, and Shaw 2012; Hammond and O'Grady 2017b; 2017a; Lenox and Kaplan 2016). Atmospheric methane data suggests that leakage rates may be much higher than reported by the NG industry (Victor 1992). GHG accounting standards are also a challenge: often, emissions are not taken into account over the entire life cycle, but only in a domestic emissions context (Le Billon and Kristoffersen 2019). This is despite the fact that emissions arise in all life cycle stages, and therefore total emissions are larger than assumed. Although there is a growing awareness of the magnitude of fugitive methane emissions, it has not yet been included in global "carbon budget" negotiations, which still focus on un*burnable* carbon. Nevertheless, aging infrastructure and insufficient environmental regulations risk the release of large volumes of un*leakable* carbon (Hendrick, Cleveland, and Phillips 2017). In Canada, for example, there is still no regulation for the reduction of flaring from NG production – companies are only required to conserve gas rather than flare it "where it is economical to do so" (Stephenson, Doukas, and Shaw 2012). Generally, data is lacking not only with regard to emissions, but also, e.g. for residential heat consumption, the current building stock, and its historical development (Bertelsen and Vad Mathiesen 2020). Governmental scenarios would also need to at least consider and calculate options without NG (Díaz, Vliet, and Patt 2017).

5.5.7 Resolving other administrative hurdles

The temporal aspects of NG use are difficult to manage, as future requirements and advantages of the sustainability transition – such as more flexible infrastructure – have not yet been properly estimated. Suitable policy instruments to manage the transition in the built environment – going beyond the widely applied principle of short-term cost optimisation – are lacking (Jeeninga and Kets 2004). This is important, as from today's perspective, *cost-optimal* and *GHG-optimal* energy systems vary significantly (Walker et al. 2019).

But even when the goal of policy intervention exists, local authorities sometimes have different interests and responsibilities than the central government, causing disagreement about strategies (Cotton, Rattle, and Van Alstine 2014). In the Netherlands, local governments do not have any legal means to force households to disconnect from the NG grid, despite a national policy goal of disconnecting all households by 2050. Due to the magnitude of that policy, doubts were raised whether it is actually possible to do so and whether local government have the capacity to steer the transition. It has also been challenging for the local authorities to engage citizens in the process (Jansma, Gosselt, and de Jong 2020).

As long as the electricity system still uses fossil fuels, the replacement of gas heating systems with electric heating systems will not be sufficient to reduce primary fossil fuel use (Walker et al. 2019). The electricity and heating system transitions therefore need to be coordinated. In addition to investment costs for appliances, supporting infrastructure investment might be necessary; for example, heat pumps require additional electricity generation and network capacities (Fais et al. 2016; Hanmer and Abram 2017; Verhagen, der Voet, and Sprecher 2020).

Historic events, such as the North Sea gas conversion in the UK, have demonstrated that major infrastructure changes can be made in a relatively short timescale. However, in this example, a state-controlled, centrally directed programme was implemented that involved strong coordination to align all the actors concerned. What is more, the energy industry was still nationalised. Often, there is no institution with the scope or authority to manage such major changes at the system level. The administrative challenge today is to find and create new sets of alliances and alignments to make such a large-scale transformation possible (Hanmer and Abram 2017).

5.5.8 Dealing with discursive lock-ins

Natural gas has been discussed since the 1970s as a "bridge fuel" by various actors, with different intentions (Delborne et al. 2020). The frame of NG as a "bridge" is a geographic metaphor that implies visible and coherent transition management; it suggests that continued economic dependence on NG and achieving a relative reduction of GHG emissions are simultaneously achievable (Cotton, Rattle, and Van Alstine 2014).

The concept of NG as a clean*er* carbon option on the one hand re-emphasises carbon as something *dirty,* and on the other hand frames it through a storyline of relative cleanliness (e.g. in comparison to coal) (Cotton, Rattle, and Van Alstine 2014). General conflict about NG use has been more pronounced in the context of hydraulic fracturing. Ultimately, it is a value conflict in which the facts and counter-facts, as well as how to interpret them, are continuously contested. The main discursive struggle is between shale gas production being seen as an *economic opportunity* vs. being an *environmental threat* (Dodge and Metze 2017). The second discursive tension is between shale gas being framed either as a "transition fuel" or a "delayer of a transition" to sustainable energy.

The characterisation of NG as a "bridge" or "transition" fuel "serves a problematic legitimizing function for natural gas development" (Stephenson, Doukas, and Shaw 2012, 452). It may obscure negative impacts, and allows policymakers to disregard the discussion on the carbon intensity of NG (Cotton, Rattle, and Van Alstine 2014). The discourse on NG has been "co-opted to legitimize the natural gas industry's interests and a jurisdiction's economic development aspirations at the expense of a considered approach to developing a sustainable energy system" (Stephenson, Doukas, and Shaw 2012, 453).

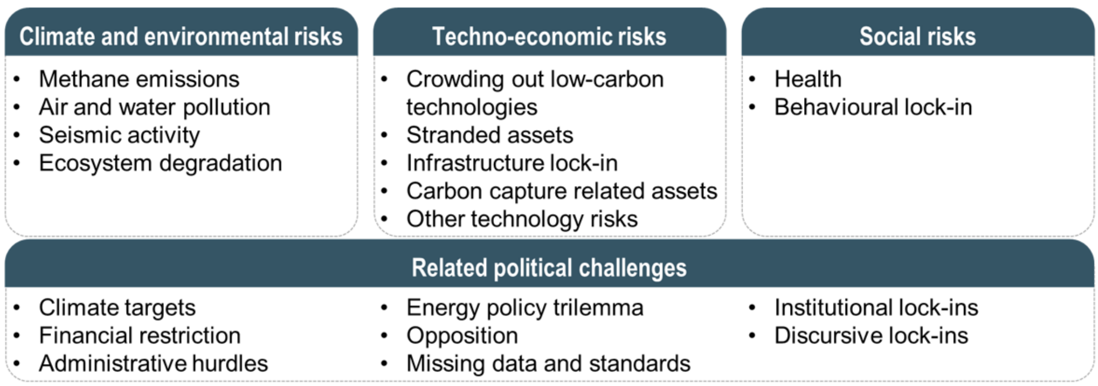
Actors and discourses can influence the approaches governments choose. Policy gridlock due to conflict and denied consensus by competing coalitions can prevent governments from taking action (Dodge and Metze 2017). Contradicting views – such as on total GHG impacts of NG – make an informed debate and decision-making much more challenging for a government (Orthofer, Huppmann, and Krey 2019).

When the discourse debate was mainly about economic opportunities on the one hand and environmental threats on the other, the general response was to govern the issue through risk governance – where the discussion mostly centred on risk thresholds or compensation payments. More fundamental questions about "whether or not the existing policy approach serve[d] long-term sustainability goals" (Dodge and Metze 2017, 6) were avoided. Alternatively, when actors shifted the meaning of shale gas from a "bridge fuel" to a "barrier to an energy transition", the common governmental response was shown to be either bans, or a search for alternative energy sources. Since this second discourse focused on more normative issues, it could not be solved by risk governance (Dodge and Metze 2017). Governments in general will have to address – and can influence – the dominant discourse debate about NG in their constituencies.

5.6 Discussion

The previously identified risks and challenges related to NG for sustainability transitions are summarised in Figure 5-6. The following section discusses the results of the mapping, highlights specific findings related to lock-in effects, and points out main research gaps.

Figure 5-6: Risks and challenges of natural gas for sustainability transitions.



The earliest study included in the mapping was published in the 1990s. Interestingly, even back then, the main uncertainties and risks surrounding methane and, hence, natural gas, were clear.

Nevertheless, 30 years after publication, the same issues continue to be discussed as controversies, and industry reporting still does not match atmospheric data of methane emissions. One particularly fascinating insight is that the paper, which focused on the transport sector in the US, included the following statement: "[T]he basic conclusions remain. The capacity to reduce greenhouse forcing in the near term through NGV switching is limited" (Victor 1992, 134–35). The "near term" in this context was 60 years, hence, ~2050. However, the framing of 2050 is now – almost 30 years later – the "long-term" period, and the perception of NG as a bridge fuel has been strengthened, rather than weakened.

So far, the papers that discuss different cases on the barriers that NG poses to energy transitions have generally received little academic attention (see Table 5-1). In addition, none of the articles included in the mapping were cited by the Fifth IPCC Assessment report (IPCC 2014), or the 1.5-degree special report (IPCC 2018), which might be an indicator that NG in general has received little attention so far for its impact on climate change.

The paper by Dodge and Metze (2017) clearly illustrated that it is politically problematic to focus discursively on the risks of NG, as the response is then more likely to be merely risk governance, and no deeper discussion about the extent to which NG use could impede progress towards climate mitigation targets. "Given the complex normative grounds on which they are founded, overcoming discourses of climate delay will require strengthened public deliberation processes that highlight responsibility, identify appropriate solutions, address social justice and ultimately show that it is both possible and desirable to mitigate dangerous climate change" (Lamb et al. 2020, 5). Therefore, as a first step towards a process of public deliberation, the following discussion focuses on the barriers that NG poses to sustainability transitions.

Even more generally, the way governments act now can limit policy choices in the future, and might thereby impose significant costs on future generations. However, when planning ahead for an upcoming phase-out with the first regulations being implemented today, costs can be constrained and political feasibility can be increased (Serkin and Vandenbergh 2018).

> *"[W]e are in the unusual position of being able to anticipate the end of the bridge even as we are building it. Are we smart enough to put policies in place that will allow it to end? Or will we lose the opportunity to construct an end to the bridge, leading to protracted conflicts and an increased chance of exceeding climate emissions reduction goals? The problem is a temporal one: Can we anticipate today the legal and political challenges to phasing out natural gas in the future?"* (Serkin and Vandenbergh 2018, 1036).

Ultimately, the mapping showed that the reason why so little action on NG (and potentially even research) has taken place concerns a set of lock-ins.

5.6.1 Lock-in effects and barriers

Seto et al. (2016) grouped lock-ins into three general categories: (1) techno-economic lock-ins; (2) political-institutional lock-ins; and (3) behavioural lock-ins. In addition, Buschmann and Oels (2019) introduced the concept of (4) discursive lock-ins. All four categories can be found in the NG mapping (see Table 5-2). These lock-ins are interconnected and often mutually reinforce each other.

Table 5-2: Four types of natural gas lock-ins.

Type of lock-in	**Lock-in mechanisms in the case of NG**
Techno-economic lock-ins	- Infrastructure, supply chains, and associated institutions are aligned in a strong and stable system - Existing infrastructures are difficult to change, especially those with long technical lifetimes and high sunk costs - Stranded assets and other negative financial consequences prevent a shift to alternatives - Crowding-out of low carbon alternatives deepens the dependence on NG - The prospect of CCS suggests a feasibility of NG use that might never become available; and even if it does, it still might not reduce emissions at the required scale - Choices mostly reflect (short-term) private, but not (long-term) social costs and benefits
Institutional lock-ins	- Interdependencies of institutions, actors, infrastructures, and markets - Political, NG industry, and social actors reinforcing the status quo favouring their interests - General stability of institutions once implemented - The role of NG for the two important goals of energy security and economic growth
Behavioural lock-ins	- Lock-in through existing structures, standards, and norms - Familiarity and satisfaction with existing gas infrastructure - Negative financial consequences due to changes - Knowledge gap of alternatives
Discursive lock-ins	- Transition fuel/bridge fuel narratives strengthening NG position - Discursive debates resulting in risk management but no substantial regulation

Most studies were about localities with existing gas infrastructure, which is a very different case than entities that are not yet dependent on NG for energy provision or revenues. Lock-ins get harder to overcome the stronger the NG related networks are, and the higher the dependence is. Deducing from the global trends of growing NG consumption and the related GHG emissions (Peters et al. 2020; Saunois et al. 2020), it seems that the lock-in mechanisms are still greater than climate change concerns.

Importantly, overcoming these lock-ins would require the debate to shift away from arguing whether NG is slightly better or slightly worse than alternatives such as coal or petrol, and instead discuss its (lack of) compatibility with both short-term and longer-term goals, as well as what else to transition towards and how.

By disregarding the impacts of NG production and consumption, as well as the effects that existing and additional NG infrastructure could have, -longer-term climate targets might be missed. Governments responsible for sustainability transitions therefore need a long-term regulatory regime which prescribes deadlines and benchmarks that would constrain or close GHG-emitting infrastructure (Chignell and Gross 2013).

5.6.2 Research gaps

Analysing the articles included in the mapping opens up a wide area for useful research: In general, it is difficult to compare alternatives across different countries. Existing research shows that each case is very different from all the others and subject to several uncertainties, including existing infrastructure, demographic change, climate conditions, governance systems and state structures, energy prices and income levels, technological developments and availability. The difficulty of drawing more specific conclusions across countries is especially clear in light of one finding of this mapping: so far, articles have mainly focused on a single industry (heating), and on only three countries (the Netherlands, the US, and the UK).

A careful weighing of costs and benefits for multiple cases, and the transition implications that arise, are not well covered by the literature. In addition, the inclusion of previous experiences and historical analyses remains rare. A particularly promising approach might be to compare experiences related to coal phase-outs (Brauers, Oei, and Walk 2020; Diluiso et al. under review), and transform the lessons learned into strategies on how to reduce NG. Identifying which institutions and general patterns played a role in other energy transitions could especially help to facilitate understandings of the position of NG in sustainability transitions.

Power aspects, incumbency, transitional aspects for workers, or, more generally, who benefits and who loses out from a reduction in NG production and consumption were not covered sufficiently to make sound decisions on transition management. Despite several studies addressing stranded asset risks and other negative consequences of reducing NG, very few studies analysed the opposition that might arise from not only industry actors, but also civil society. The influence of framing and the discourses related to this opposition would also merit further research. Another crucial factor is that the citation count of the papers included in the mapping shows how little attention the topic has generally received so far. The lack of awareness is, therefore, another important aspect for researchers and decision-makers to take into account.

In the context of slow developments and lock-ins with rapid changes to total GHG levels, the deliberate acceleration of transitions is an important field for more articles (see e.g. Roberts and Geels (2019)). Articles could analyse what an accelerated NG phase-out would require and how this could be managed.

From a more technical perspective, it would be interesting to look at the impact a generally warmer climate would have on the performance of gas-fired power plants. Moreover, it would be important to obtain data on GHG emissions including methane leakages, as well as the economics of NG production separate from oil production. The links between those two sectors might pose another lock-in effect for NG. In general, studies have so far disregarded the impact a reduction of NG use would have on the industry and transport sectors; case studies on the diverse forces of NG lock-in are also still lacking (with the exception of an article on LNG projects in Germany, Brauers et al., forthcoming).

5.7 Conclusion

This systematic literature mapping analyses the question of what evidence exists in the sustainability transitions literature on the potential risks and adverse effects of continuing to use natural gas. After discussing the methodological approach of the mapping, this paper described the publication statistics of the articles included, followed by results on climate and environmental risks, techno-economic risks, and social risks, as well as political challenges. The discussion focused on the resulting lock-in effects and the barriers to successful sustainability transitions. This mapping can also provide directions for future research and some initial guidance for policymakers on what to look out for when designing their respective transition strategies.

The main climate and environmental risks were found to be methane emissions (and in particular methane leakages), air and water pollution, seismic activity, and ecosystem degradation related to NG production and use. The main techno-economic risks included the crowding out of low-carbon technologies, stranded assets, infrastructure lock-in, and carbon capture uncertainty, as well as a few other risks. I found that the main social risks arise from health impacts and behavioural lock-ins. The resulting political challenges lie mainly in achieving GHG emission reduction targets, balancing the energy policy dilemma, handling opposition to NG reduction, determining the right level of financial support, managing missing data and standards, and resolving other administrative hurdles, as well as dealing with discursive lock-ins.

The mapping also shows that the potential of NG to reduce GHG emissions is small, and, in the long-term, climate targets cannot be achieved via NG use. It also illustrates that there is little research regarding the barrier NG poses in potentially delaying the sustainability transition, particularly on societal and political challenges. Existing research is focused on the Netherlands, as well as the United Kingdom and the United States, and mainly addresses the heating sector. This might also be because only literature in English was included in the search.

The mapping has several potential limitations: Critiques about the risks related to NG may be hidden in a paper, and unapparent in the abstract, only to emerge in the discussion on NG later on. The paper would then not have been part of the systematic mapping because of the inclusion criteria. Due to the research design, no articles were included that focus on alternatives to NG, such as synthetic gases or electrification. However, those papers might also contribute to understanding the potential drivers of and barriers to NG use. Another possible limitation due to the research design is that no grey literature such as reports by NGOs were included. Those would potentially have voiced more concerns than purely academic papers, as well as suggesting ways on how to overcome lock-ins. Due to the focus on risks, no overview of the advantages of natural gas, potentially justifying a certain extent of natural gas use, are included in the map. One methodological limitation is that – as this is a single-author paper – no consistency checks of the coding, normally part of a rigorous systematic mapping, were conducted to validate the coding procedure. Similarly, only backward and no forward snowballing of references was added to the search in the databases.

The current political debate on NG is very different from the picture created by this literature map. It might be where the debate on coal was until the early 2010s: A similar discourse on coal as a transition fuel existed, and concerns revolved mainly around energy security and stability, the economic (in)feasibility of a phase-out, and the social hardships it would cause. If climate targets are to be met, the debate in academia and politics needs to move quickly from incremental GHG emission mitigation and whether it is necessary to reduce NG, to how to manage the challenges of a transition away from gas. Such plans would need clear policy targets such as those in the Dutch heating sector, and instruments such as detailed phase-out plans, as well as support for the actors affected. Acknowledging that NG poses a barrier to successful sustainability transitions is the first step.

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6 Appendices of individual chapters

6.1 Appendix Chapter 2

6.1.1 History of hard coal in Germany

After the Second World War, Germany was divided into West and East Germany. The entire hard coal production was based in West Germany and in underground mines. From 1947, Saarland, the second largest mining region after the Ruhr area, was occupied by the French military regime, which also controlled the coal production. In 1957, Saarland returned to Germany politically and in 1959 economically. The remaining mining areas were Aachen and Ibbenbüren, respectively. Our analysis focuses both on the largest mining area Ruhr area and the Saarland. For West Germany, the domestic hard coal reserves were more than just an energy carrier since it helped to rebuild its industry and enabled it's so called "economic miracle" (Plumpe 2016, 261–62). Furthermore, coal helped to reintegrate (West) Germany into an international union: The European Coal and Steel Community (ECSC), the predecessor of the European Union, was founded in 1951 together with Italy, Belgium, France, Luxemburg and the Netherlands.

After the end of the war, the price for domestic coal was fixed to a comparatively low level in order to facilitate the reconstruction of Germany. In 1956, the ECSC forced Germany to free the price and implement a market based system for the German coal price (Nonn 2009, 97–98). This liberation of the energy sector combined with the end of the Suez crisis led to cheap import oil gaining significance and to a declining hard coal demand. This was the beginning of the 1958 coal crisis. Additional to the substitution by oil, domestic coal was increasingly under pressure by comparably cheap foreign hard coal. The coal and steel industry (in German 'Montanindustrie') formed a powerful network together with influential unions and politicians (especially the social democratic party), protecting domestic coal production. At this time, coal did not only have regional significance for workers and the economy but guaranteed security of supply of energy which made it a strategic good. Hence, and to prevent structural disruptions, the German hard coal sector received subsidies to balance the price gap between domestic and imported coal since 1968. Since 1964, the prices for domestic coal exceeded the ones of imported coal (Verein der Kohleimporteure e.V. 2017, 111).

Hard coal was responsible for more than 70% of West Germany´s primary energy consumption (PEC) in 1950 (2.9 TJ).[103] In the following, hard coal was increasingly substituted both in absolute and relative terms: Before the reunification mainly with imported mineral oil, natural gas, and nuclear power, and after the reunification also renewable energy. Coal's share decreased to 19% of PEC in 1990 and 11% in 2017. From 1950 onwards Germany's PEC increased, to almost 13.6 TJ in 2017 (AG Energiebilanzen e.V. 2018b).

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[103] AG Energiebilanzen e.V. 2017. 'Zeitreihen bis 1989'. https://ag-energiebilanzen.de/12-0-Zeitreihen-bis-1989.html.

Hard coal consumption in the electricity sector of West Germany reached its highest share with over 60% at the end of the 1950s, was ~30% at the time of reunification and ~15% for Germany in 2017 (AG Energiebilanzen e.V. 2018a). Gross electricity generation (GEG) in West Germany increased from 44 TWh in 1950 to

450 TWh by 1990.[104] Germany's GEG in 2017 was almost 655 TWh.[105] For a more detailed description see Herpich, Brauers, and Oei (2018).

Besides the increasing amount of imported energy carriers, the ongoing mechanization of the mining sector led to a lower employment which had an additional impact on the total number of employees in the two mining regions. At the peak, right before the coal crisis in 1958, over 600,000 people were employed. Until 1968, 320,000 people lost their job. The development of employment in hard coal mining as well as produced and imported hard coal is depicted in Figure 6-1.

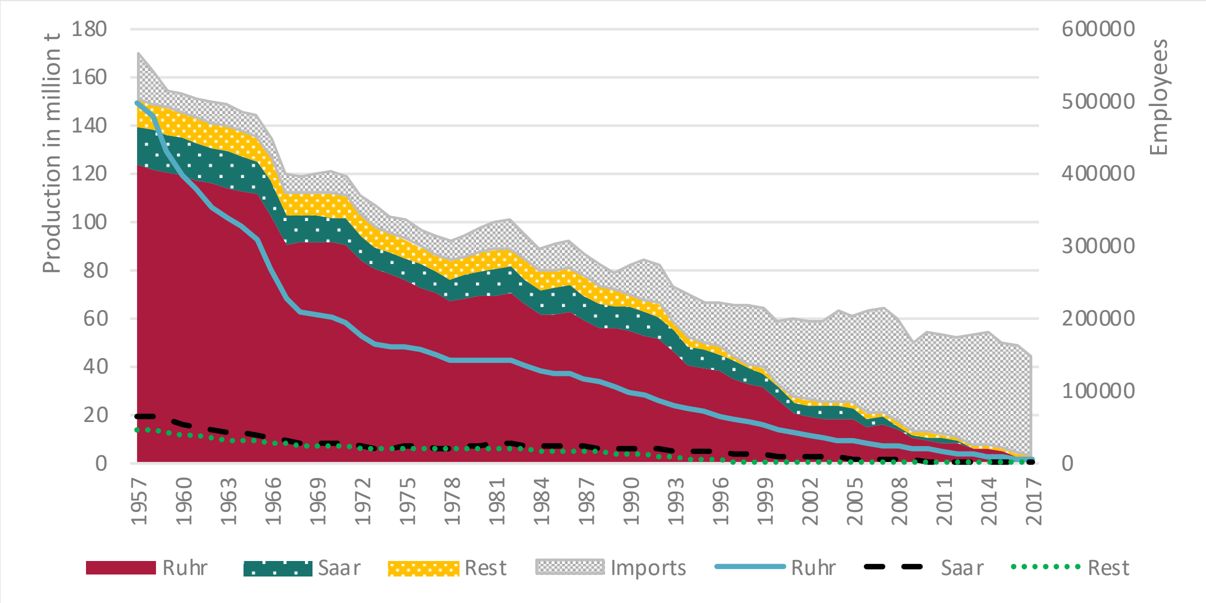

Figure 6-1: Domestic hard coal production, imports and employees (mining only) of West Germany

Source: Own calculations based on Statistik der Kohlenwirtschaft and Verein der Kohleimporteure.[106]

Note: Production is displayed as stacked areas, employment as independent lines.

Due to the coal and steel industry, the NRW became the country with the highest population. The industry concentrates on the Ruhr area. The Ruhr area is still the most densely populated area in

[104] Statistik der Kohlenwirtschaft e.V. 2017. 'Bruttostromerzeugung'. https://kohlenstatistik.de/17-0-Deutschland.html.

[105] AG Energiebilanzen e.V. 2018. 'Bruttostromerzeugung in Deutschland ab 1990 nach Energieträgern' https://ag-energiebilanzen.de/index.php?article_id=29&fileName=20171221_brd_stromerzeugung1990-2017.pdf.

[106] Statistik der Kohlenwirtschaft e.V. 2018a. 'Steinkohle'. Statistik der Kohlenwirtschaft. http://www.kohlenstatistik.de/18-0-Steinkohle.html, Statistik der Kohlenwirtschaft e.V. 2018b. 'Steinkohle - Belegschaft im Steinkohlebergbau'. Steinkohle. https://kohlenstatistik.de/18-0-Steinkohle.html, Verein der Kohleimporteure e.V. 2017. 'Jahresbericht 2017 - Fakten und Trends 16/17'. Hamburg, Germany. http://www.kohlenimporteure.de/publikationen/jahresbericht-2017.html and Verein der Kohleimporteure e.V. 2017.

Germany – until today. In the Saarland the industries gather in the south. Both mining regions depended strongly on the economic circumstances of this industry and suffered repeatedly of high unemployment rates over the years. Total unemployment in West Germany fell from around 1.9 million in 1950 to just 150,000 in 1962.[107] The rising development of the metal industry was able to cover most of the job losses in the mining sector in NRW (Nonn 2001, 179f). The Saarland profited from an emerging automotive industry. Yet, in the following years, the "economic miracle" ended and the mining regions as well as Germany as a whole suffered from global macroeconomic changes like the oil crises in 1973 and 1979. The induced economic recessions led to a doubling of the unemployment rates in the Ruhr area (see also Figure 2-2) within only a few years (1973: 1.6% → 1974: 3.3% and 1979: 5% → 1982: 10.3%). A first peak in unemployment was reached with 15.1% in 1987, which dropped to around 10% in the early 90s. In 2005, a new maximum was reached with 16.4%. In the past 10 years, the region's average unemployment rate equates to approximately 11%. The development of the unemployment figures corresponded with the trends of NRW and the rest of Germany; however, unemployment rates of the Ruhr area were always higher. The gap widened especially in the 1980s, where they were between 5 and 7% higher than the West German average. The gap was reduced to only about 2% in 2002 and remains at a level between 4 and 5% since 2010.[108] The Saarland's variation of the unemployment rate was similar to the Ruhr area's during the oil crises but was constantly above it (1973: 1.9% → 1976: 6.7% and 1979: 6.5% → 1983: 11.8). In the late 1990´s, the unemployment of the Saarland started to develop better than the rest of Germany, and is currently at around 8% (which is close to the federal level, see Figure 2-2).

6.1.2 Political instruments since the 1950s until today

Looking at both regions' unemployment rates, especially in recent years, shows that the transition in the Saarland seemed to have a more positive effect on development. The following section analyses the pathways of the two case study regions including the implemented measures and policies, in order to derive possible explanations for the different developments. Both regions strongly relied on coal as well as steel production. Hence, the (socio-)economic crises in the affected regions as well as the implemented measures cannot simply be attributed to the coal sector alone.

6.1.2.1 Coal crises and first structural policy programs in the 1950s and 60s

The whole reduction and transition process in Germany was highly influenced by the "coal and steel co-determination law" ("Montanmitbestimmungsgesetz") from 1951, giving the employee-side equal number of votes in executive boards. All measures that were implemented within the companies along the decline in production were agreed on by the workers. This law did not account for the Saarland from the beginning, since it was independent from Germany and occupied by the French military regime. When the Saarland was returned to West Germany in 1957, the Saarbergwerke AG was founded (state

'Jahresbericht 2017 - Fakten und Trends 16/17'. Hamburg, Germany. http://www.kohlenimporteure.de/publikationen/jahresbericht-2018.html.

[107] Bundesagentur für Arbeit. 2018. 'Arbeitslose und Unterbeschäftigung - Deutschland und West/Ost (Zeitreihe Monats- und Jahreszahlen ab 1950)'. Bundesagentur für Arbeit - Statistik. https://t1p.de/vkfp.

[108] Regionalverband Ruhr. 2017c. 'Arbeitsmarkt'. https://t1p.de/2v1v.

company owned to 74% by West Germany and 26% by Saarland) (Roos 2007, 101). As a first response to the coal crisis in 1958, shifts were shortened and employees entered early retirement, financially supported by the state (Farrenkopf 2009, 81, 94). In the short-term, these measures were able to alleviate negative consequences for affected workers, however, between 1957 and 1967, over 300,000 out of 600,000 workers lost their job in hard coal production (~267,000 in the Ruhr area and ~23,400 in the Saarland). The first years of the reduction in coal production due to the oil crisis overlapped with the last years of the “economic miracle” in Germany. The majority of the workers were therefore able to transfer into other jobs, mainly in the metal industry (Nonn 2001, 179f). Thus, unemployment payments were only necessary for workers close to their retirement.

In order to be able to control the decline of coal production, mining companies in the Ruhr area were forced to combine their production in a newly founded company called RAG AG (Goch 2009, 128). In the Saarland, hard coal was already produced almost entirely by the Saarbergwerke AG, but the production sites were connected in order to increase their productivity. Additionally, in 1968, the German coal sector concluded sale contracts with the energy and steel sector. These contracts included state subsidies, paying the price difference between domestic and imported hard coal, to enable a structured and slowed down decline in coal production and related employment.

In the same year, the structural policy program “Development Program Ruhr” was launched with a volume of Deutsche Mark (DM) 17 billion (€8.7 billion)[109] (Goch 2009, 146). The government of NRW acknowledged the need for an economic reorientation as domestic coal production kept declining and unemployment rose. Hence, it bundled hitherto individual and isolated measures in this structural program which intended to attract new enterprises from other sectors. The influential mining and steel companies opposed these plans by not providing the land they owned to new coming companies as they feared losing qualified workers and increasing wage levels in the region (called “ground lock”, “Bodensperre”).

Another objective of this program was to improve education and traffic infrastructure to enable the economic reorientation (Goch 2009, 146). Previously, there existed no university in the area. Furthermore, historically cities grew around the mining and steel industry, so that homes of workers were in close distance to their workplaces. Connections between neighboring cities needed to be improved in order to enable the citizens to accept alternative jobs in a wider area (Bogumil et al. 2012, 15).

After the reintegration into Germany, the Saarland faced additional challenges: Due to the special status as occupied state, the Saarland was not considered by the payments granted by the Marshal plan and needed state aid between 1956 and 1961 of DM2.8 billion (€1.4 billion) of which DM500 million (€ 256 million) were spent on economic and industrial policies (Anderson 2007, 148). At this time, the Saarland highly depended on coal and steel production, with 36% of total workforce in mining and 43% in the metal industry in 1957 (Anderson 2007, 145). Thus, when the coal crisis started, the federal efforts went

[109] If not stated otherwise the values in this paper are in nominal terms in the respective currency.

into supporting especially the coal industry to alleviate social problems but with the effect of conserving structural weaknesses in the economy (Dörrenbächer, Bierbrauer, and Brücher 1988, 209). Regardless of political measures, between 1960 and 1970 jobs in mining declined from 53,000 to below 27,000.[110]

Similar to the Ruhr area, the highway system in the Saarland was extended in the early 1960's (Fläschner and Hunsicker 2007, 86). The Saarland followed a strategy to structure the decline in hard coal production and simultaneously diversify the economic activity of the Saarbergwerke AG in the mid-1960s (including oil and refining, chemical industry and construction of coal-fired power plants) (Marx 2014, 260–62). The efforts lacked a broader strategy, which is why the projects were not sustainable and failed (Roos 2007, 104). During the recession between 1966 and 1968, the Saarland was hit exceptionally hard compared to the rest of Germany – every 10th job in manufacturing was lost (in the rest of West Germany every 14th) (Anderson 2007, 150). On the one hand, this was a result from the neglection by the Marshall plan, on the other hand from overcapacities that developed under the French occupation when the production focused on the French market (Dörrenbächer, Bierbrauer, and Brücher 1988, 209). Therefore, in 1969, the "Structural Program Saar" was implemented with the goal to achieve full employment by creating 50,000 jobs and overcome the differences between the regional and federal economic development. The strategy contained elements to strengthen the coal and steel sector as well as to increase the employment in other growth sectors. One element was to extend the riverbed of the river Saar, in order to enable the transportation of bulk goods for the coal and steel industry (Anderson 2007, 150).

At the same time, the individual mass motorization took place in Germany and car manufacturers and suppliers were eager to enter and expand into the European market (Fläschner and Hunsicker 2007, 89). The Saarland had the right circumstances for car manufacturers as it was able to provide qualified workers from the mining and steel industry and sufficient space for new companies was made available (Giersch 2007, 134). In the Saarland, the mining companies only received set-aside premiums for producing less coal if they offered their real estates for new commercial usage. The resistance against new companies might additionally have been lower compared to the Ruhr area, since the mining company that produced almost the total amount of coal in the Saarland, was in public ownership.

The "Structural Program Saar" (later transferred into the "Action Program Saarland-Westpfalz") was designed for 5 years with a volume of DM40 million (€20.5 million) (Anderson 2007, 153). The Saarland granted companies tax cuts, low interest rates and premiums (Evenhuis 2016, 164). Due to these benefits and the close distance to the car manufacturers in South Germany, suppliers and manufacturers (e.g. FORD) settled in the Saarland. Between 1960 and 1972 around 140 companies settled in the Saarland, most of them in the last 5 years (Giersch 2007, 133). In total, around 40,000 new jobs were created, 25,000 of those in newly settled companies (Anderson 2007, 153). As a consequence, gross GDP rose up to a quarter between 1970 and 1975 and the wage level of Saarland assimilated to the average West German level. Due to this boom, in the end of the 1960s and early

[110] Statistik der Kohlenwirtschaft e.V. 2017. 'Steinkohle - Belegschaft im Steinkohlebergbau'. Steinkohle. 2017. https://kohlenstatistik.de/18-0-Steinkohle.html.

1970s, the „Structural Program Saar“ proved to be very successful (Dörrenbächer, Bierbrauer, and Brücher 1988, 209; IHK Saarland 1976, 15f).

6.1.3 The oil & steel crises and resulting industrialization policies in the 1970s

The strategy of economic reorientation failed in the Ruhr area and unemployment increased significantly from 12,000 in 1970 to almost 100,000 in 1976.[111] The economic miracle ended and the "ground lock" prevented new companies from settling. In the following, the new approach was to strengthen the local potential by modernizing the *existing* industries (coal, steel and energy) with investments of DM2 billion (€1 billion) in total (Goch 2009, 150). The investments into the coal and energy sector were partly driven by the hope of a renaissance of coal after the first oil crisis in 1973. The situation in the Ruhr area further aggravated with also led to the steel industry crisis of 1974. One of the largest consumers of domestic hard coal had reached its peak and was not able to recover. Politicians realized the structural nature of this crisis and demanded adjustments on the production level.

After the second oil crisis in 1979, unemployment further increased and problems associated with the high sectoral specialization of the coal and steel regions became obvious. Between 1980 and 1984 the structural policy program "Action Program Ruhr" was implemented in order to initiate the economic reorientation of the Ruhr area and the establishment of new industries. The program created incentives for technology transfers between universities and companies. Additionally, the program intended to develop the tertiary sector in the Ruhr area. It connected individual measures in different fields such as technology, innovation support, ecology, culture and the labor market and was supposed to coordinate the numerous measures by the federal government, the state and the municipalities. The program with a volume of DM6.9 billion (€3.5 billion) followed a new principle that emphasized the participation of regional stakeholders in order to lower their resistance in the transformation process (Goch 2009, 152).

As part of the program, the "state development society" ("Landesentwicklungsgesellschaft") and the property fund Ruhr were implemented to buy and restore former industrial sites. This measure ended the "ground lock" and, hence, was able to overcome a major barrier against economic reorientation. [112] Thanks to the "Action Program Ruhr" several new technology centers were created and the soft location factors (e.g. improving the regional image, more cultural activities, etc.) improved. Nevertheless, similar to previous programs it did not succeed in diversifying the economy. One reason for that was the large investment into the modernization programs of the *existing* industries.

The steel crisis hit the Saarland as well in 1973/74, resulting in an increase of the unemployment rate and 60% of the 54,000 workers in the steel industry lost their jobs within 20 years (Lerch and Simon 2011, 30). At this time, the Saarland had difficulties to attract further industries and companies due to currency disparities and a shift of production to countries with lower wage levels (Dörrenbächer,

[111] Regionalverband Ruhr. 2017c. 'Arbeitsmarkt'. 2 October 2017. http://www.metropoleruhr.de/fileadmin/user_upload/metropoleruhr.de/01_PDFs/Regionalverband/Regionalstatistik/Arbeit_und_Soziales/Arbeitsmarkt/2015_Zeitreihe_Arbeitsmarkt.pdf.

[112] metropoleruhr. 2010. 'Bodensperre'. Regionalkunde Ruhr. 2010. http://www.ruhrgebiet-regionalkunde.de/html/aufstieg_und_rueckzug_der_montanindustrie/huerden_des_strukturellen_wandels/bodensperre.php%3Fp=4,1.html.

Bierbrauer, and Brücher 1988, 209). Thus, the idea was to strengthen or at least stabilize the employment by creating high quality jobs (Dörrenbächer, Bierbrauer, and Brücher 1988, 209). Like in the Ruhr area, the first oil crisis lighted up the hope of a revitalization of the coal industry and the production rose. After the second oil crisis, the hard coal production rose even further and reached the highest productivity in Europe (Dörrenbächer, Bierbrauer, and Brücher 1988, 213). The Saarland, despite being considerably smaller, spend twice as much as in the Ruhr area on research of alternative coal usages.

Between 1978 and 1981, the Saarland received around DM180 million (€92 million) via the special steel program of the GRW[113] (Nägele 1996, 101). With high state aids, the diversification of the Saarbergwerke was supposed to help creating high quality jobs (Dörrenbächer, Bierbrauer, and Brücher 1988, 213). Similar to the Ruhr area, the Saarland tried during this time to conserve the old structures. One the one hand, this can be interpreted as some kind of social instrument as it slowed down the decrease in employment but on the other hand this measures can be seen as intervention which delayed necessary structural change (Otto and Schanne 2006). An important factor throughout the crises were the close ties of the up- and down-stream industries of the automotive industry (Georgi and Giersch 1977). Due to these ties, many companies stayed within the region regardless of the crisis. Additionally, the ongoing incentives for investments proved to be helpful for the expansion of existing industries (Giersch 2007).

6.1.4 Regionalization of the structural policy since the mid-1980s

Policymakers had realized that there was no single industry likely to replace the steel and coal sector in a way so that it could stabilize the Ruhr area's economy alone. Previous programs did not take the individual strengths and weaknesses of cities into account. The new more regionalized approach to structural policy included regionally planned development strategies, conducting individual strengths and weaknesses analyses of cities and regions (Goch 2009, 156). After the second oil crisis in 1979, the unemployment rate almost tripled within 6 years to 14.2% – compared to a rate of 8.7% in the rest of the country.[114] The NRW state government implemented the so-called "Commission for Coal and Steel Regions" (Komission Montanregionen) which included regional stakeholders in the process of developing strategies. In 1987, the program "Future Initiative Coal and Steel Regions" (Zukunftsinitiative Montanregionen) with a volume of DM2 billion (€1.0 billion) was launched. Innovation and technology funding, education of workers, infrastructure and improvement of the environment as well as energy matters were announced as important fields of development. In order to receive funding, the regions now had to submit projects themselves, which were developed together with regional stakeholders such as the chamber of crafts, unions or environmental organizations.

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[113] The GRW („common task for improving the regional economy") is the cohesion and exchange scheme between the states in Germany. It was founded in 1969 and concentrates on structurally weak regions.

[114] Regionalverband Ruhr. 2017c. 'Arbeitsmarkt'. October 2, 2017. http://www.metropoleruhr.de/fileadmin/user_upload/metropoleruhr.de/01_PDFs/Regionalverband/Regionalstatistik/Arbeit_und_Soziales/Arbeitsmarkt/2015_Zeitreihe_Arbeitsmarkt.pdf.

The “International Building Exhibition Emscher Park” project from 1989 to 1999 is another example for consent-based regionalized policy. 120 small projects were combined, mostly targeting the improvement of soft location factors in order to create a new identity of the Ruhr area. These projects with a total budget of DM5 billion (€2.6 billion) included measures to implement an underground sewage system, cultural and touristic projects, 17 technology centers and the remediation of mining damages (Goch 2009, 162). It opened up new spaced both for people and nature and improved quality of living in the region.

Several universities and research institutions as well as an image beyond mining and steel was created by these structural policy programs. Although that improved the attractiveness of the region, only a limited number of new companies, and hence employment opportunities, was attracted into the Ruhr area. Most financial support by the state was still focused on protecting the coal and streel industry as a powerful network of the related companies, unions and politicians resisted more rapid changes.

In the Saarland, decision makers realized that despite the oil crises hard coal as well as steel production would not recover. One major problem of these industries were the high dependence on global economic events and that resulting crises were detrimental for the economy. Hence, the original plans to further expand the coal sector was given up in 1982 (Roos 2007, 106). The demand for coal in the energy sector decreased due to further deployment of nuclear power and also the demand in the steel sector shrunk due to the shift of production to other countries and replacement of steel by aluminum and plastics (Dörrenbächer, Bierbrauer, and Brücher 1988, 214f). The support for the steel sector impacted the public household of the Saarland - between 1980 and 1985, DM1.5 billion (€0.8 billion) were spent on steel sector support. The state and federal spending on regional policy equaled to DM770 million (€ 394 million) during this time (Anderson 2007, 155). Unemployment was the highest of all states in Saarland at this time. Nevertheless, support via the GRW for the Saarland was cut. Therefore, in 1983, the Saarland launched its own program with a volume of almost DM39 million (€20 million) which mimicked the measures of the GRW by aiming at business attraction and investment support (Anderson 2007, 157).

In addition, the Saarland government addressed the predecessor of the EU for financial support and consequently received funding via the RESIDER and RECHAR programs for coal and steel regions. Funds were granted for redevelopment of the environment, restauration of former industrial sites as well as reeducation programs for worker in the affected regions (Evenhuis 2016, 168)[115].

At the end of the 1990s, the Saarland followed a new path and founded research facilities connected to IT, bio- & nano-technology as well as medicine in order to develop an innovation intense and growth orientated economy (Lerch 2007, 128). The IT research facilities were the only ones affecting the labour market. The main reason for failure in the other sectors were limited independency or responsibility of the subsidiary companies of globally acting corporations that were settled in the Saarland. The possibility

[115] European Commission. 1997. ‘Kommission gewährt 6,2 Mio. ECU für RECHAR-II-Programm im Saarland’. Cordis: Forschungs- & Entwicklungsinformationsdienst Der Gemeinschaft. 24 July 1997. https://cordis.europa.eu/news/rcn/5387_de.html.

to create a cooperation between research and production leading to the development of new products was therefore limited (Otto and Schanne 2006, 135; Lerch 2007, 128).

6.1.5 EU's growing influence and end of subsidies for domestic hard coal production in the 2000s

In 1997, the Saar government sold the Saarbergwerke AG to the RAG AG as part of the coal compromise between the federal government and the mining states. Therefore, the Saarland received additional financial resources to deal with the expected reduction of another 12,000 jobs. At this time, the economic development in the Ruhr area and Saarland increasingly focused on the technological development and innovation, and support for entrepreneurship and start-ups (Evenhuis 2016, 169). Research centers were founded and extended; start-ups were granted financial support and received consulting from institutions that intended to ease the technology transfer between businesses and research facilities. Around the turn of the millennium, the growing influence of the EU and its shifted objective from erasing regional disparities towards economic growth emphasized the support of so called clusters, meaning networks of institutions, companies and research facilities operation in promising economic sectors (Lageman and Schmidt 2007).

In 2007, the EU´s competition regulations forced Germany to implement a law to end the coal subsidies until 2018. A total volume of around €289 to 331 billion from 1950 to 2008[116] was spend on hard coal (Meyer, Küchle, and Hölzinger 2010, 10). The annual costs for the sale subsidies for hard coal exceeded the average salary of a coal mining employee at this time. The costs increased from €13,500 in 1980 to €75,000 in 2005 (Frigelj 2009, 230).

When the end date for the subsidies was negotiated, measures to ensure social security for workers were one of the focus points. Every person formerly employed in hard coal production entered retirement, got other social benefits or a new job ("Steinkohlefinanzierungsgesetz"). During the hearings in 2007, the mining industry, unions and social democrats pleaded for 2018 as the production end date. Their main arguments were the "social compatibility" for workers and necessary adjustment time for the entire Ruhr area. The year 2012 was also discusses as possible end year. The IG BCE union stated that 11,000 employees would then lose their job, while research facilities like University Duisburg-Essen and the Leibniz Institute for Economic Research (RWI) stated that this could have avoided €4-10 billion in mining damages and subsidies. These funds could have been used to reeducate former employees, with up to almost €1 million per worker to create a "socially compatible" phase-out (Frigelj 2009, 229–30).

The end date of coal mining subsidies was eventually set to 2018, also thanks to the powerful network of unions, the mining industry and the social democrats. In the Saarland, the end date was initially planned to be 2014, but as the region suffered from mining related earthquakes, the fear of further damages rose and mining ended in 2012 (Hartmann 2018, 316). The remaining workers were transferred to the coal mining area at Ibbenbüren. Every worker with the age of 42 or older was secured

[116] In real terms in 2008 €. Upper value includes financial support (direct and tax breaks), benefits in the emissions trade system and the costs of higher electricity prices through incomplete competition in the electricity sector.

by law against unemployment. After the end of their employment in coal mines, workers would work three years in decommissioning and then receive payments for 5 years to bridge the time until they enter the regular pension fund at age 62 in 2027 (Frigelj 2009, 229). The federal parliament estimated the total costs for the phase-out period from 2006 to 2018 at around €38 billion.[117] Additionally, the parliament estimated around €2 billion for pensions and mining damages and additional €7 billion for the so-called eternity costs after 2018 (Frigelj 2009, 214).

[117] Bundesregierung. 2007. 'Drucksache 557/07 des Deutschen Bundestages - Gesetzesentwurf zur Finanzierung der Beendigung des subventionierten Steinkohlenbergbaus zum Jahr 2018'.

6.2 Appendix Chapter 3

6.2.1 Description of the situation of coal in Poland

Figure 3-1 gives an overview of coal mining and the total number of employees in coal mining (hard coal and lignite) in Poland for the last decades. It becomes apparent that coal's importance is in slow decline. Despite the reduction of coal mining and employment since the 1960s, the share of electricity generated by coal is still more than 75% (Central Statistical Office of Poland 2019). Additionally, Figure 3-1 shows that since the 1990s, employment in coal mining has been reduced from almost 390.000 employees to around 82.000 (in 2018), while mining output was only reduced from little more than 215.000 tonnes in 1990 to around 122.000 in 2018. Coal consumption has stabilised in recent years and without further measures to reduce coal production and consumption climate protection commitments will be missed. Poland is the EU country with the most open coal mines (21 hard coal mines and 5 lignite mines). 37 coal-fired power plants remain with a capacity of ~25 GW. Coal jobs in 2017 are estimated to around 105.000, with ~92.000 in coal mining and 13.000 in power plants (Alves Dias et al. 2018). Poland's coal power plants are relatively old and inefficient: 62 percent of Poland's coal capacity is more than 30 years old (IEA 2016). More than 50% of the total installed capacity is expected to come offline between 2020 and 2035. Four coal-fired units are currently being discussed and under construction, while one was commissioned in December 2017 (RAP 2018).

Mining was the first sector where a modern social security system was introduced in Poland, involving social activities like running hospitals, schools or kindergartens. The political importance of the mining sector in turn created more state involvement and subsidies. Coal exports enabled the development of the national economy and protected the country from the oil crisis in the 1970s. Nevertheless, from the 1980s onwards, the problems of the Polish energy sector, which decreased the entire economy's competitiveness, became evident (World Energy Council 2014, 169). After 1990, the collapse of large unprofitable coal mines and related unemployment hit Poland hard. The first policy programme targeting the coal industry from 1990-1995 prevented bankruptcies, supported the closure of inefficient mines and stabilised production and exports. The programme from 1996-2000 closed 20 inefficient collieries and was the first one to reduce employment and production substantially (Jonek Kowalska 2015). Employment in Polish coal mining fell from 240,000 in 1998 to 140,000 in 2002 (Suwala 2010).

About 50 percent of all Polish hard coal mines are unprofitable. If Poland keeps mining at today's speed, resources in currently open lignite coal mines will be depleted in the next 20 to 30 years. Whether new lignite mines will be opened can be questioned, as local opposition is rising (Forum for Energy Analysis 2016). Imports have increased, from around 2 million tonnes in 1995 to 13 million tonnes in 2017, with 65% coming from Russia. More than 70% of the coal imports are thermal coal used for electricity and heat generation (Szpor and Ziółkowska 2018; Alves Dias et al. 2018).

The Polish state is heavily involved in the coal industry: The state has shares in all but two mines of the country, in seven of the nine mining companies, and also in electricity generators, coal traders, and coal investment companies (Forum for Energy Analysis 2016). Four companies dominate the electricity market: PGE, Tauron, Energa, and Enea, involved in distribution, generation and retail of electricity. All four are publicly traded but nevertheless state-controlled, with 30 to 58 percent shares owned by the

Polish government. The most important mining companies are PGG, the biggest hard coal mining company in Europe, and JSW, the largest coke producer in the EU (OECD 2016).

The coal sector is, in contrary to most other sectors, almost fully unionised. All three major trade unions in Poland – Solidarność, OPZZ and Forum FZZ – are strongly politicised, covering the whole political spectrum. Next to these big trade union confederations thousands of company level unions exist (Trappmann 2012). Around 13,000 strikes occurred in Poland in 2008.

The pro-coal mind-set of the government is seen in various statements and documents (Ceglarz, Benestad, and Kundzewicz 2018), e.g. the development strategy from 2017, which identifies coal as crucial for Polish energy security still for the next decades (Kuchler and Bridge 2018). Under the new PiS government, (partly) state-owned utilities were forced to form the new mining group PGG (rescuing various other mining companies from bankruptcy (EIA 2016; Ancygier and Szulecki 2016). As a consequence, PGG bought KW, formerly Europe's largest coal mining company, and later merged with KHW. The debt of the entire coal sector amounted to around €3.4 billion at the end of October 2015. Additional financial support for PGG emerged from state-owned investors PGNiG, PGE, Enea, Energa and TF Silesia, creating an even stronger link between mining and electricity generation (Polityka Insight 2017; Kuchler and Bridge 2018). The European Commission approved €1.8 billion in state aid for the time period between 2015 and 2018 to restrict environmental and social impacts of mine closures by 2018 (van der Burg 2017). The newly founded "Platform for Coal Regions in Transition" by the European Commission is perceived by the Polish government as an opportunity to develop and apply so called 'clean coal technologies'.

NGOs are fighting plans for coal mine and power plant extensions increasingly with lawsuits. E.g. in northern Poland the new 1.6 GW Polnoc coal plant construction was stopped because the judge ruled that the district authority did not adequately consult stakeholders on the project. A similar lawsuit stopped Engie's plans for the 500MW Leczna plant (Darby 2016).

6.2.1.1 Competition by alternative electricity generation

Since 1990, there was no serious competition for coal. Due to energy security concerns, domestic energy carriers were the preferred choice. As no major natural gas or oil reserves were accessible, Poland relied on domestically available hard coal and lignite. Plans for nuclear power plans were repeatedly postponed and/or cancelled since the 1980s. The last drop-out of nuclear power plant plans was PGE in May 2018.

Natural gas provided only a small share in energy supply (5% of Polish electricity generation in 2016), as it needed to be imported from Russia. Since the construction of a Liquefied Natural Gas (LNG) terminal in 2015, imports from other states, like e.g. Norway, are available. Although this might increase natural gas consumption, it is limited by current LNG terminal capacities. Furthermore, as fossil gas still has a greenhouse gas (GHG) content comparable to coal, it would be a short sighted investment.

With 14%, renewables had a low share in Polish electricity generation in 2016, especially compared to the rest of the EU: Solar provided less than 0.5% of Polish electricity and onshore wind 8% (IEA 2017b). The 2016 act on the investments in wind power plants effectively removed the possibility to build new onshore wind turbines. Next to limiting the space for new turbines it has also meant a three- to four-fold increase in property taxes. Together with the drop in green certificate values, investments came to a halt. While 1,260 MW were installed in 2015, only a 41 MW were added in 2017 (Polityka Insight 2017; ICIS 2018). However, there is an ongoing debate about changing the law back to the former status (ICIS 2018) and to introduce new tenders for both onshore and offshore wind.

Plans for Polish offshore wind projects are coming closer to completion: PSE, the Polish transmission system operator, estimates that 4 GW offshore wind capacity could come only by 2027. As PSE and PGE (one of the project developers) are both state-owned and an offshore wind energy commission has been installed in November 2017, a shift is visible by the Polish government's approach to renewables.

6.2.2 Additional material TEF

6.2.2.1 Additional explanation methodology

Firms within an industry regime are, despite being autonomous, shaped by the industry regime, containing joint industry-specific institutions, mind-sets, belief systems, mission, identity, norms, technical knowledge and capabilities as well as formal-regulatory institutions (e.g. regulations, taxes, subsidies) (Kungl and Geels 2018; 2016).

Externally-oriented responses towards the economic environment include economic positioning strategies, innovation strategies, corporate political strategies and discursive framing strategies. *Internally-oriented* strategy approaches determine how a firm adapts by changing firm-related characteristics. Geels argues that firms introduce incremental changes once problems can no longer be denied. The efforts include e.g. operational changes, efficiency improvements or cost-cutting. Once performance problems are no longer seen as temporary but as structural, firms take more radical approaches. If unsuccessful, a deep-restructuring of firms' core beliefs and identities takes place, which ideally leads to the development of new business models, core competencies and values. This process of change highlights that mind-sets and missions are the most difficult to change, while technological and regulatory regime elements are comparatively easier to modify (Kungl and Geels 2016; Geels 2014a).

A destabilisation is a multi-dimensional process with various (sequential) external pressures and responses of the industry regime. Single pressures are unlikely to have a large impact, however, an adding-up of pressures in both environments and alignment in their directionality can destabilise an industry (Kungl and Geels 2018).

6.2.2.2 Illustration of selected TEF results for Poland

Figure 6-2 and Figure 6-3 illustrate the TEF findings, both the influences of the environments on the coal regime and the following response strategies for the time period 2015-2018.

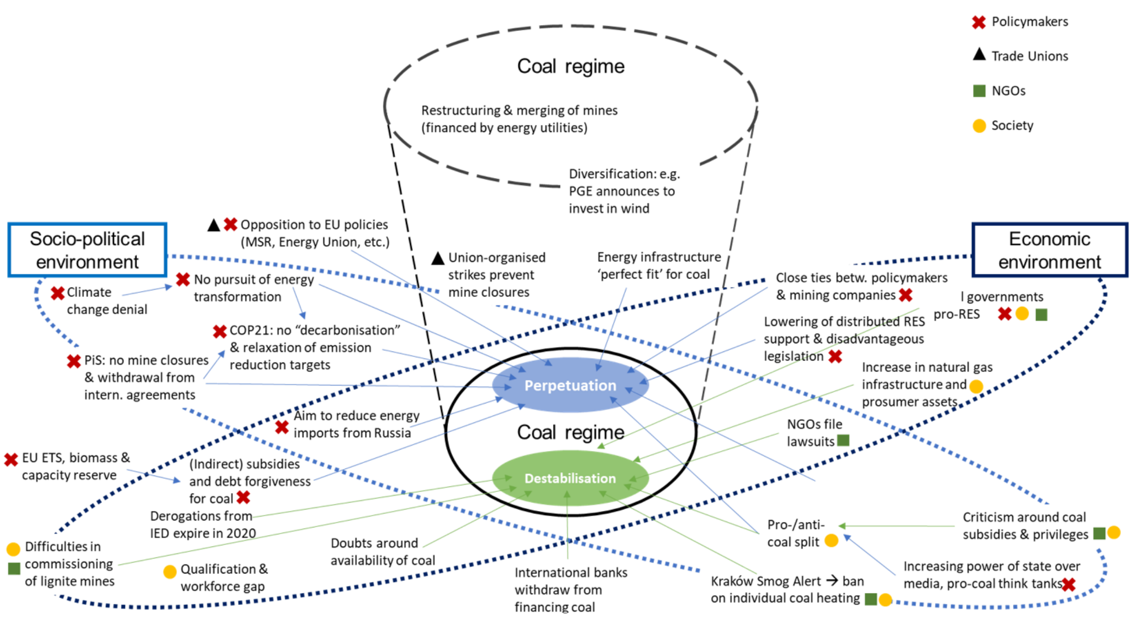

Figure 6-2: Coal regime analysis 2015-2018.

Source: Authors' illustration based on Hoppe (2018).

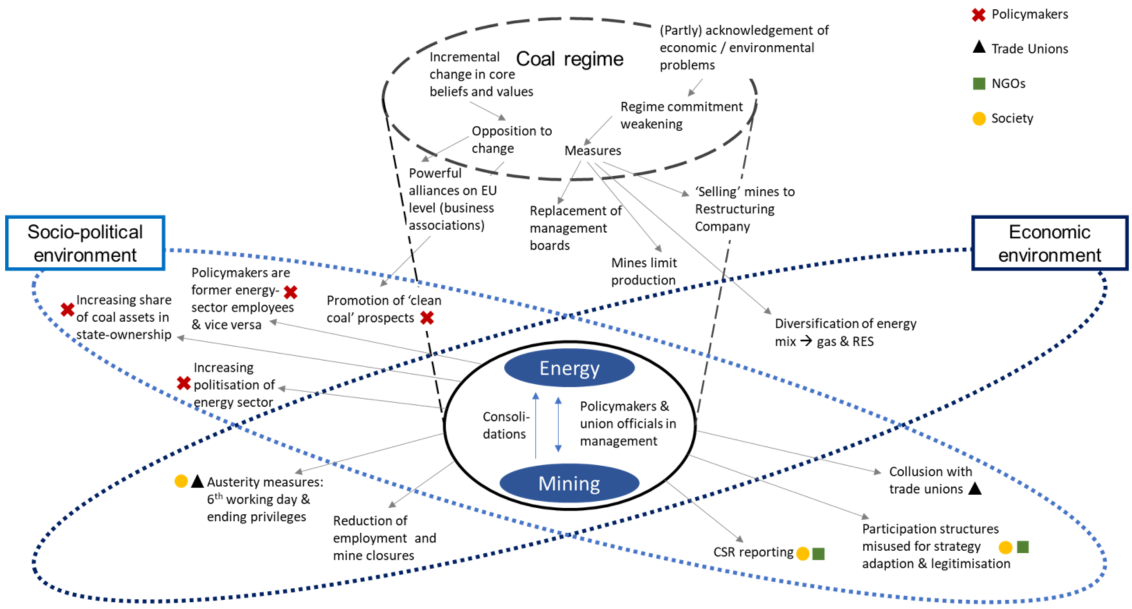

Figure 6-3: External and internal response strategies 2015-2018.

Source: Authors' illustration based on Hoppe (2018).

6.2.2.3 Data collection for the TEF

We analysed the accumulated information in a qualitative interpretive approach, similar to all other TEF applications that we are aware of. The data was collected within the period 2016 – 2019, observing the energy transition in Poland to understand ongoing developments. To gain a deeper understanding of the Polish situation we had several informal background discussions with Polish stakeholders on research visits to Warsaw, Łódź and Katowice in 2017 and 2018, involving industry, civil society and academia representatives. Also, we want to thank several Polish scholars examining the energy sector, with whom we have been in continuous exchange. Each claim we make in the paper, has been referenced to the specific peer-reviewed paper, newspaper report, database entry, or press statement. In total we collected and analysed more than 600 documents, mostly written in English or German. Most documents included in the paper, however, are secondary/academic literature, as we cannot read Polish. The most important primary sources were:

- Databases like the Polish Central Statistical Office, such as their data on Environment and Energy: https://stat.gov.pl/en/topics/environment-energy/; or a range of Concise Statistical Yearbooks from various years (2000-2019); see e.g. Figure 3-1.
- Official government plans that were available in English, such as the energy strategy Poland: “ENERGY POLICY OF POLAND UNTIL 2040” by the Ministry of Energy https://www.gov.pl/attachment/376a6254-2b6d-4406-a3a5-a0435d18be0f
- Company reports such as annual reports to check for their profitability over the years, including PGE, PGG, JSW; or PG Silesia providing context on their history: http://www.pgsilesia.pl/en/about-us/history.
- Blogs such as: https://www.polishsmogalert.org/ but also euracoal; and newspaper articles e.g. from the Warsaw Business Journal (https://wbj.pl/), euractive, the economist and Reuters articles on Poland

6.3 Appendix Chapter 5

Table 6-1: Elements of the search string.

natural gas (below with OR)	transition (below with OR)
fossil gas*	transformation*
natural gas*	shift*
LNG	energy transition*
shale gas*	sustainability transition*
	multi-level perspective
	multi level perspective
	MLP
	technological innovation system*
	TIS
	phase-out*
	phasing out
	phase out*
	sustainability theor*
	socio-technical scenario*
	sociotechnical scenario*
	socio-technical transition*
	sociotechnical transition*
	societal transition*
	sustainability transition*
	transition theor*
	energy system transition*
	radical innovation*
	system innovation*
	niche management
	switch*
	transition fuel*
	transitional fuel*
	bridge fuel*
	bridging fuel*
	bridge-fuel*
	bridge techn*
	bridging techn*
	destabilisation*
	destabilization*
	decarbonis*
	decarboniz*
	lock-in*
	locking in
	locking-in
	low-carb*
	zero carbon
	zero-carbon
	climate neutral*
	climate-neutral*
	path-depend*
	path depend*

Table 6-2: Portals, databases, and search terms used.

Portal	Databases	Search term	Date of query	No. of results
Web of Science	Science Citation Index Expanded (SCI-EXPANDED) Social Sciences Citation Index (SSCI) Arts & Humanities Citation Index (A&HCI) Conference Proceedings Citation Index- Science (CPCI-S) Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH) Book Citation Index– Science (BKCI-S) Book Citation Index– Social Sciences & Humanities (BKCI-SSH) Emerging Sources Citation Index (ESCI)	(TITLE-ABS-KEY ((“fossil gas*”) OR (“natural gas*”) OR (LNG) OR (“shale gas*”) OR (CNG))) AND (TITLE-ABS-KEY ((transformation*) OR (shift*) OR (“energy transition*”) OR (“sustainability transition*”) OR (“multi-level perspective”) OR (“multi level perspective”) OR (MLP) OR (“technological innovation system*”) OR (TIS) OR (phase-out*) OR (“phase out*”) OR (“phasing out”) OR (“phase out*”) OR (“sustainability theor*”) OR (“socio-technical scenario*”) OR (“sociotechnical scenario*”) OR (“socio-technical transition*”) OR (“sociotechnical transition*”) OR (“socio-technical energy transition*”) OR (“sustainability transition*”) OR (“transition theor*”) OR (“energy system transition*”) OR (“radical innovation*”) OR (“system innovation*”) OR (“niche management”) OR (switch*) OR (“transition fuel*”) OR (“transitional fuel*”) OR (“bridge fuel*”) OR (“bridging fuel*”) OR (“bridge-fuel*”) OR (“bridge techn*”) OR (“bridging techn*”) OR (decarboniz*) OR (decarbonis*) OR (lock-in*) OR (“locking in”) OR (locking-in) OR (low-carb*) OR (“zero carbon”) OR (zero-carbon) OR (“climate neutral*”) OR (climate-neutral*) OR (path depend*) OR (path-depend*))) NOT (TITLE-ABS-KEY ((contracept*)))	13 October 2020	3,131
Proquest	ABI/INFORM Collection Applied Social Sciences Index & Abstracts (ASSIA) Digital National Security Archive ERIC PAIS Index Periodicals Archive Online Periodicals Index Online Sociological Abstracts Worldwide Political Science Abstracts	((“fossil gas*”) OR (“natural gas*”) OR (LNG) OR (“shale gas*”) OR (CNG)) AND ((transformation*) OR (shift*) OR (“energy transition*”) OR (“sustainability transition*”) OR (“multi-level perspective") OR (“multi level perspective”) OR (MLP) OR (“technological innovation system*”) OR (TIS) OR (phase-out*) OR (“phase out*”) OR (“phasing out”) OR (“phase out*”) OR (“sustainability theor*”) OR (“socio-technical scenario*”) OR (“sociotechnical scenario*”) OR (“socio-technical transition*”) OR (“sociotechnical transition*”) OR (“socio-technical energy transition*”) OR (“sustainability transition*”) OR (“transition theor*”) OR (“energy system transition*”) OR (“radical innovation*”) OR (“system innovation*”) OR (“niche management”) OR (switch*) OR (“transition fuel*”) OR (“transitional fuel*”) OR (“bridge fuel*”) OR (“bridging fuel*”) OR (“bridge-fuel*”) OR (“bridge techn*”) OR (“bridging techn*”) OR (decarboniz*) OR (decarbonis*) OR (lock-in*) OR (“locking in”) OR (locking-in) OR (low-carb*) OR (“zero carbon”) OR (zero-carbon) OR (“climate neutral*”) OR (climate-neutral*) OR (path depend*) OR (path-depend*)) NOT ((contracept*))	12 October 2020	18
Business Source Complete	INCLUDED: Journal Articles, Books Excluded: Newspapers, Market Research Reports, Industry Profiles, Product Reviews, Country reports, SWOT Analysis	((“fossil gas*”) OR (“natural gas*”) OR (LNG) OR (“shale gas*”) OR (CNG)) AND ((transformation*) OR (shift*) OR (“energy transition*”) OR (“sustainability transition*”) OR (“multi-level perspective”) OR (“multi level perspective”) OR (MLP) OR (“technological innovation system*”) OR (TIS) OR (phase-out*) OR (“phase out*”) OR (“phasing out”) OR (“phase out*”) OR (“sustainability theor*”) OR (“socio-technical scenario*”) OR (“sociotechnical scenario*”) OR (“socio-technical transition*”) OR (“sociotechnical transition*”) OR (“socio-technical energy transition*”) OR (“sustainability transition*”) OR (“transition theor*”) OR (“energy system transition*”) OR (“radical innovation*”) OR (“system innovation*”) OR (“niche management”) OR (switch*) OR (“transition fuel*”) OR (“transitional fuel*”) OR (“bridge fuel*”) OR (“bridging fuel*”) OR (“bridge-fuel*”) OR (“bridge techn*”) OR (“bridging techn*”) OR (decarboniz*) OR (decarbonis*) OR (lock-in*) OR (“locking in”) OR (locking-in) OR (low-carb*) OR (“zero carbon”) OR (zero-carbon) OR (“climate neutral*”) OR (climate-neutral*) OR (path depend*) OR (path-depend*)) NOT ((contracept*))	12 October 2020	1,898

Table 6-3: Journal distribution.

Journal	**Number of articles**
Energy Policy	10
Energies	3
Energy	3
Applied Energy	2
Climate Policy	2
Energy Research & Social Science	2
Environmental Research Letters	2
Building Research & Information	1
Clean Technologies and Environmental Policy	1
Climatic Change	1
Energy and the Environment	1
Energy Economics	1
Energy Procedia	1
Energy Strategy Reviews	1
Environment and Planning A: Economy and Space	1
Frontiers in Energy Research	1
Futures	1
Journal of Industrial Ecology	1
Journal of Cleaner Production	1
Journal of Environmental Policy & Planning	1
Journal of Power and Energy	1
Journal of the Air & Waste Management Association	1
Minnesota Law Review	1
Natural Gas & Electricity	1
Renewable and Sustainable Energy Reviews	1
Science of the Total Environment	1