The Political Economy of Energy Transitions

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Abstract

Mitigating climate change is among the largest challenges for humanity in the 21^{st} century. With the Paris Agreement, an overwhelming majority of states pledged to limit the global temperature increase to well below 2°C, and ideally, 1.5°C above pre-industrial levels. Many countries have translated these pledges into the goal of reducing emissions to net-zero, while global efforts to curb emissions increased gradually. However, with current climate policies in place, temperature levels will exceed the aspired targets. Implementing climate policies that reduce emissions and trigger low-carbon innovation is urgent, which requires understanding which climate policy instruments and their design options effectively reduce carbon emissions. Yet, whether the implementation of effective climate policies is politically feasible hinges on political economy factors. Understanding the political economy of energy transitions is thus crucial for successful climate policy making. This dissertation explores the interplay between design options of effective climate policy instruments and the political economy affecting their implementation.

The four central chapters of this dissertation analyze the impact of market-based climate policies on low-carbon investments, how political economy factors affect coal deployment in multiple emerging economies including India, and narratives in the emerging discourse around hydrogen. The chapters provide the following key insights: First, a sufficiently high price floor in emissions trading systems would lead to higher low-carbon investment of especially green companies, while fossil investment of energy-intensive companies would be abolished. Second, the continued deployment of coal-fired power plants is shaped by political actors that try to meet the goals of economic growth, energy system stability, and low energy prices, but policymakers are also subject to the influence of the power sector. Third, ensuring a sufficient supply and the long-term availability of electricity motivates private and public coal investments in India, while regional coal jobs and established local vested interests pose major barriers for a prospective coal-phase out. Fourth, actors in the emerging hydrogen discourse share the goal of establishing a hydrogen economy, but conflicts emerge around the sectors in which hydrogen shall be used, around the envisaged production methods, and the desirability of imports.

The findings entail the following implications for ongoing academic and political discussions: Ex-ante evidence provided by German energy managers suggest that price floors at sufficiently high levels would be important extensions of emissions trading systems. The findings complement previous ex-post studies on the effectiveness of the European Union Emissions Trading System that, until recently, were constrained by data from periods with low certificate prices, preventing predictions about possible impacts of higher prices. An expert survey about political economy factors in major coal countries highlights that there are political economy patterns that consistently occur across countries and thus, require special consideration in discussions about global coal phase-out policies. These findings also add to scant insights on the political economy in emerging economies. Detailed insights from expert interviews on Indian energy politics suggest that regional phase-out plans ensuring a just transition and restructuring the power system are both important measures to initiate a coal phase-out. Finally, the analysis of the emerging public discourse on hydrogen using German newspaper articles provides first empirical insights of narratives used by different actors, and lays the ground for an enhanced

understanding of current and potential upcoming controversies. A simple conceptual framework thereby contributes to theorizing sustainability transitions that span across multiple sectors.

Overall, this dissertation combines insights on the design of climate policy instruments with the political economy around coal and hydrogen across different geographical contexts. Two chapters on Germany assess how design options for carbon pricing policies may affect low-carbon investments of firms, while analyzing the discourse around hydrogen emphasizes how narratives may influence the public perception around a low-carbon energy carrier. The findings underline the stark role of politics in setting economic incentives for low-carbon investment decisions, but also that the implementation of energy policies may be strongly debated and contested. Another two chapters focus on coal politics in several emerging economies and especially India, and highlight the complex challenges for domestic policymakers in these countries that aspire to foster coal phase-outs. Both chapters outline the trade-off arising between environmental goals and short term economic growth but also point to the role of vested interests and lobbying. All chapters jointly show that understanding both politics and policy instruments in conjunction are of utmost importance for successfully mitigating climate change.

Zusammenfassung

Die Verminderung des Klimawandels ist eine der größten Herausforderungen der Menschheit im 21. Jahrhundert. Mit dem Übereinkommen von Paris (*Paris Agreement*) hat sich eine überwältigende Mehrheit der Staaten dazu verpflichtet den globalen Temperaturanstieg auf deutlich unter 2°C, und idealerweise auf unter 1,5°C des vorindustriellen Niveaus zu begrenzen. Viele Länder haben ihre Zusage in das Ziel der Klimaneutralität (*net-zero emissions*) übertragen, und globale Bemühungen Emissionen zu reduzieren sind schrittweise erhöht worden. Allerdings wird der Temperaturanstieg unter der aktuellen Klimapolitik die angestrebten Ziele überschreiten. Die Umsetzung von Klimapolitikmaßnahmen, welche Emissionen reduzieren und kohlenstoffarme Innovationen fördern, ist dringend erforderlich, was ein Verständnis davon erfordert, welche klimapolitischen Instrumente und deren Gestaltungsoptionen effektiv Emissionen reduzieren. Ob die Umsetzung effektiver klimapolitischer Maßnahmen politisch durchsetzbar ist, hängt jedoch von politökonomischen Faktoren ab. Ein Verständnis der politischen Ökonomie von Energiewenden ist daher entscheidend für erfolgreiche Klimapolitik. Diese Dissertation untersucht das Zusammenspiel zwischen den Gestaltungsoptionen effektiver klimapolitischer Instrumente und der politischen Ökonomie ihrer Implementierung.

Die vier Hauptkapitel dieser Dissertation analysieren die Auswirkungen marktwirtschaftlicher Klimapolitikinstrumente auf kohlenstoffarme Investitionen, wie politökonomische Faktoren den Bau von Kohlekraftwerken in mehreren Schwellenländern inklusive Indien beeinflussen, sowie die Narrative im beginnenden Diskurs um Wasserstoff. Die Kapitel beinhalten folgende zentrale Erkenntnisse: Erstens würde ein ausreichend hoher Mindestpreis in Emissionshandelssystemen zu höheren kohlenstoffarmen Investitionen führen, insbesondere von grünen Unternehmen, während fossile Investitionen energieintensiver Unternehmen abgeschafft würden. Zweitens wird der Bau weiterer Kohlekraftwerke maßgeblich von politischen Akteuren bestimmt, welche versuchen die Ziele Wirtschaftswachstum, ein stabiles Energiesystem und niedrige Energiepreise zu erreichen, wobei die politischen Entscheidungsträger*innen dabei dem Einfluss des Stromsektors unterliegen. Drittens reizen die Sicherstellung einer ausreichenden Stromversorgung und die langfristigen Verfügbarkeit von Strom private und öffentliche Kohleinvestitionen in Indien an, während regionale Kohlearbeitsplätze und lokale Interessen einen möglichen Kohleausstieg erschweren. Viertens teilen die Akteure des beginnenden Wasserstoffdiskurses das Ziel des Aufbaus einer Wasserstoffwirtschaft. Jedoch entstehen Konflikte darüber, in welchen Sektoren Wasserstoff eingesetzt werden soll, zu den geplanten Produktionsmethoden und der Bewertung von Importen.

Aus den Ergebnissen leiten sich folgende Implikationen für weitere wissenschaftliche und politische Diskussionen ab: Ex-ante Daten von deutschen Energiemanager*innen legen nahe, dass ein Mindestpreis auf ausreichend hohem Niveau eine wichtige Erweiterung von Emissionshandelssystemen wäre. Die Ergebnisse ergänzen frühere ex-post Studien zur Effektivität des Europäischen Emissionshandelssystems, die bis zuletzt durch Daten aus Zeiträumen geringer Zertifikatspreise eingeschränkt waren, was Vorhersagen zu möglichen Auswirkungen höherer Preise erschwerte. Eine Expert*innenenbefragung zu politökonomischen Faktoren in wichtigen Kohleländern zeigt, dass es in allen Ländern gleichermaßen auftretende politökonomische Strukturen gibt, welche daher eine besondere Berücksichtigung in Diskussionen

über globale Kohleausstiegsstrategien erfordern. Die Ergebnisse erweitern außerdem die bregrenzten Erkenntnisse zu der politischen Ökonomie in Schwellenländern. Detaillierte Einblicke durch Expert*inneninterviews zur indischen Energiepolitik legen nahe, dass regionale Kohleausstiegspläne, die sowohl eine gerechte Transition, als auch eine Umstrukturierung des Stromsystems gewährleisten, wichtige Maßnahmen zur Einleitung eines Kohleausstiegs sind. Zuletzt liefert die Analyse des beginnenden öffentlichen Diskurses um Wasserstoff auf Basis von deutschen Zeitungsartikeln erste empirische Erkenntnisse über die Narrative verschiedener Akteuren und legt den Grundstein für ein besseres Verständnis aktueller, sowie potenzieller zukünftiger Kontroversen. Ein einfacher konzeptioneller Rahmen leistet dabei einen Beitrag zur Theoriebildung von Transitionen zur Nachhaltigkeit, welche sich über mehrere Wirtschaftssektoren erstrecken.

Insgesamt kombiniert diese Dissertation Erkenntnisse über die Gestaltung klimapolitischer Instrumente mit der der politischen Ökonomie von Kohle und Wasserstoff in verschiedenen geografischen Kontexten. Zwei Kapitel zu Deutschland untersuchen wie sich Gestaltungsoptionen der Kohlenstoffbepreisung auf kohlenstoffarme Investitionen von Unternehmen auswirken können, während die Analyse des Wasserstoffdiskurses unterstreicht, wie Narrative die öffentliche Wahrnehmung eines kohlenstoffarmen Energieträgers beeinflussen können. Die Ergebnisse heben die wichtige Rolle der Politik bei der Bestimmung wirtschaftlicher Anreize für kohlenstoffarme Investitionsentscheidungen hervor, aber auch, dass die Umsetzung von Energiepolitik stark umstritten und umkämpft sein kann. Weitere zwei Kapitel befassen sich mit der Kohlepolitik in verschiedenen Schwellenländern und insbesondere Indien, und heben die komplexen Herausforderungen von politischen Entscheidungsträger*innen in diesen Ländern hervor, die einen Kohleausstieg anstreben. Beide Kapitel umreißen den Zielkonflikt zwischen Umweltzielen und kurzfristigen Wirtschaftswachstums, verweisen jedoch auch auf die Rolle persönlicher Interessen und Lobbyismus. Gemeinsam zeigen alle Kapitel, dass ein Verständnis des Zusammenhangs von Politik und Politikinstrumenten von größter Bedeutung für eine erfolgreiche Eindämmung des Klimawandels sind.

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doubt or frustration. I look back to four inspiring and challenging years, and now forward to new tasks and experiences.

Contents

Chapter 1

Introduction

1 Introduction

1.1 Climate change mitigation

Mitigating climate change is one of the largest challenges for humanity in the 21^{st} century. Although this challenge has by today been widely acknowledged, and efforts to reduce greenhouse gas (GHG) emissions gradually increase, it remains open at which level temperatures will eventually stabilize or peak. Future temperature levels will be decisively influenced by the effectiveness of climate policies. Implementing climate policies in turn requires understanding political economy aspects.

This section outlines the status quo of climate change mitigation efforts. The following parts first provide a general overview of the challenges around climate change mitigation, and outline implications of potential socioeconomic pathways (1.1.1). These pathways are then contrasted by the status quo trajectories and drivers of current emissions (1.1.2). By showing the gap between current international climate mitigation efforts, and efforts required to sufficiently curb emissions (1.1.3), I motivate why the subsequent section assesses the effectiveness of climate mitigation policies.

1.1.1 The climate challenge and carbon costs

With the Paris Agreement in 2015, in total 196 states pledged to limit the increase in the global average temperature to well below 2°C above pre-industrial levels, and to ideally 1.5°C (United Nations, 2015). Exceeding these temperature targets would lead to severe climate impacts, such as more frequent heatwaves, heavy precipitation and associated flooding, more intense droughts, tropical cyclones, sea level rise and coastal flooding (IPCC, 2021). In 2021, the temperature has already increased by 1.1°C compared to 1850-1900 (IPCC, 2021), while the global atmospheric concentration of carbon dioxide has increased from roughly 320 ppm in 1960, to 410 ppm in 2019 (Friedlingstein et al., 2020).

The carbon budget concept allows to relate future carbon emissions to corresponding temperature levels. The IPCC quantifies the remaining carbon budgets from the beginning of 2020 available to limit global warming to 1.5 (2)°C with a likelihood of 50% as 500 (1.350) $GtCO_2$, and 83% as 300 (900) $GtCO_2$, respectively (IPCC, 2021).[1] The relationship between cumulative CO_2 emissions in the atmosphere and expected global mean temperatures is approximately linear. With assumed constant annual emissions from 2018 of 58 $GtCO_2eq$ (Lamb et al., 2021), the budget available to limit the temperature increase to 1.5°C (300 $GtCO_2$, 83%) would be used up before the year 2027, and 2°C (900 $GtCO_2$, 83%) in 2036. However, there is a risk that a global cascade of tipping points could lead to additional carbon emissions that further increase global warming beyond temperatures that, without these additional emissions, would stabilize between 1 to 2°C (Lenton et al., 2019).

The point in time when the carbon budgets for specific temperature targets will be depleted depends on future emissions. Several scenarios outline different emission pathways with outcomes depending on a variety of influencing factors. The IPCC

[1]However, estimates of the remaining global carbon budget differ between sources and are subject to uncertainty (Rogelj et al., 2019; IPCC, 2021).

distinguishes between five *Shared Socioeconomic Pathways* (SSPs) that, among other factors, rest on different assumptions on socio-economic factors and levels of climate change mitigation (IPCC, 2021). The SSPs are narratives that describe socioeconomic trends affecting future societies that face low to high challenges for climate change mitigation and adaptation (Riahi et al., 2017). The scenarios result in different GHG emissions, namely very low and low (SSP1-1.9 and SSP1-2.6), intermediate (SSP2-4.5), and high and very high (SSP3-7.0 and SSP5-8.5) (IPCC, 2021). The very likely temperature increase in the very low scenario ranges between 1.0°C to 1.8°C, between 2.1°C to 3.5°C in the intermediate scenario, and between 3.3°C to 5.7°C in the very high scenario. Keeping the temperature increase below 1.5°C is thus generally still possible, but a rapid decrease of annual carbon emissions would be decisive. The temperature increases in most IPCC scenarios are at odds with the Paris Agreement. Depending on the scenario, a temperature increase of 1.5°C is expected within the next 20 years, and without rapid emission reductions, in the early 2030s (IPCC, 2021). The Intergovernmental Panel on Climate Change (IPCC) thus concludes that immediate, rapid and large-scale reductions of greenhouse gas emissions are necessary to limit global warming to close 1.5°C, or at least 2°C (IPCC, 2021).

Attempts to economically quantify the impacts of increasing global temperatures resulted in the concept of social costs of carbon (SCC). The SCCs quantify the economic costs of emitting an additional unit of GHG emissions as the net present value, including both direct market impacts, but also non-market impacts, such as environmental and health costs. Correctly determining SCCs would theoretically allow to deduct socially optimal investments and policies to reduce GHG emissions, and to derive socially optimal carbon prices. Higher SCCs generally imply higher societal returns of investments into emission reductions, and thus suggest more stringent climate policies.

Since the 1990s, multiple estimates of SCCs have been presented and critically summarized within several review papers, and by the IPCC (Pearce et al., 1996; Tol, 2005, 2012; van den Bergh and Botzen, 2014). The estimated SCCs, which are quantified via Integrated Assessment Models, vary widely. For example, a review on SCCs from 2005 shows a median estimate of USD 14 per ton of CO_2, although 5% of the studies estimated SCCs of USD 350 per ton of CO_2, or higher (Tol, 2005). A more recent meta-analysis, in contrast, shows a mean value of USD 55 per ton of CO_2 within a range of USD -13 to 2387 per ton of CO_2, and finds higher SCC estimates for more recent and peer-reviewed studies (Wang et al., 2019). Differences in estimates are affected by assumptions about the included cost categories, uncertainties about damage costs and risk aversion, and especially the discount rate (Tol, 2005; van den Bergh and Botzen, 2014). Which methodological assumptions are appropriate to determine the level of SCCs remains unresolved and debated (van den Bergh and Botzen, 2015; Diaz and Moore, 2017; Tol, 2018; Kaufman et al., 2020).

The models used to calculate SCCs also suggest economically optimal temperature targets. A particularly influential, and controversial, estimate stems from the nobel price winner William Nordhaus, who finds an optimal temperature increase of 3.5°C until 2100, using his Dynamic Integrated Climate–Economy (DICE) model (Nordhaus, 2019), which significantly exceeds the goals set in the Paris Agreement. Kalkuhl and Wenz (2020) use empirical historical data to quantify climate impacts on the gross regional product, and estimate that such a temperature increase would reduce the global economic output by 7-14% in 2100, while damages in some regions would be even higher. Others demonstrate the sensitivity of the outcomes to model dynamics and parameter estimates by updating the DICE model's carbon cycle, energy balance model, damage function and discount rates, which then provides to optimal climate policy pathways consistent with the Paris Agreement (Hänsel et al., 2020). Some critiques even question the entire value of Integrated Assessment Models, arguing that the input parameters would be arbitrary, and the findings generally too imprecise (Pindyck, 2013). Despite apparent difficulties and controversies around calculating SCCs and determining optimal temperature targets, there is a broad consensus that annual greenhouse gas emissions need to decrease compared to the status quo.

1.1.2 Drivers of carbon emissions

Understanding where and why emissions grow is key to develop strategies for climate change mitigation. In 2018, 40% of global GHG emissions stem from East Asia and North America, mostly from China and the United States. However, especially emissions from emerging economies in Southern Asia, the Middle East, Eastern Asia, and Eurasia have grown relatively fastest since 2010 and thus become increasingly important. Decomposing carbon emissions via the Kaya identity shows that economic growth (absolute and per capita) and population growth are the major contributors (Lamb et al., 2021).

Emissions by supply sector can be distributed with 34% to energy systems, 24% to industry 21% to agriculture, forestry and other land use, 14% to transport and 6% to the operation of buildings (Lamb et al., 2021). From a supply side perspective, energy systems remain the most important contributor of global carbon emissions and the fastest growing sector. Energy system thus build the most important entry point for decarbonization. The power sector, comprising coal, gas and other plants producing electricity and heat, accounts for 71% of overall 20 $GtCO_2eq$ emissions related to energy systems in 2018. The importance of energy systems, and of power generation in particular, will further increase with the ongoing electrification of the other economic sectors, which is required to achieve the net-zero emissions goal (Davis et al., 2018). The allocation of energy system emissions to these demand sectors, which use the produced electricity and heat, would already now increase the emission shares for industry to 35%, and that of buildings to 17% (Lamb et al., 2021).

Within the power sector, the operation of coal-fired power plants remains the most relevant emission source, severely endangering international climate targets (Edenhofer et al., 2018; Tong et al., 2019). Besides mitigating climate change, phasing-out coal would furthermore provide direct environmental and health benefits (Rauner et al., 2020). However, coal retains its relevance, despite a decrease of capacity planned or under development since 2015, difficulties to obtain finance, decreasing costs for renewables, impacts of the Covid-19 pandemic, and an increasing number of countries having net-zero pledges (Global Energy Monitor et al., 2021). In 2020, there were still 180 GW of coal under construction and another 323 GW planned (Global Energy Monitor et al., 2021). The same year, mostly emerging economies in South East Asia and beyond also deployed, constructed or planned new coal-fired power plants, namely China, India, Bangladesh, the Philippines, Vietnam, Indonesia, Turkey, South Africa and Japan. China alone built 76% of the total new coal coal capacity, and thereby largely contributed to a net increase of the global coal capacity by 12.5 GW, which would have shrunk otherwise. Yet, even when only considering emissions of coal-fired power plants deployed before 2018, meeting the 1.5 (2) degree target would still require a lifetime reduction from a historical average lifetime of approximately 50 years, to 20 (35) years (Cui et al., 2019). Phasing-out coal before its economic lifetime will thus become a next big challenge. Future coal emissions will, most importantly, stem from fast growing emerging economies, such as China and India, but possibly also from developing countries in sub-Sahara Africa (Steckel et al., 2015, 2020).

Preventing the deployment of additional coal-fired power plants and phasing out-coal also in emerging economies is thus essential to mitigate climate change. To satisfy the growing energy demand of emerging economies, it would in turn require the uptake of clean energy sources, and most of all, a rapid deployment of renewable energies (see Section 6.2.2 for further discussions). The following section discusses the status quo of international climate mitigation efforts, and outlines the gap between efforts required to meet the goals set by the Paris Agreement, and trajectories of existing policies.

1.1.3 International mitigation efforts

The primary mechanism in the Paris Agreement are the Nationally Determined Contributions (NDCs). The NDCs describe the national efforts of all countries that ratified the Paris Agreement to limit the global temperature increase to well below 2°C and ideally 1.5°C. Every country is expected to increase the ambition of its NDCs every five years. Studies evaluating the NDCs show that it is very unlikely that countries under current policies will meet their NDCs (Liu and Raftery, 2021), and that even fully implemented NDCs, would most likely be insufficient to limit warming to 2°C (Peters et al., 2017; Liu and Raftery, 2021).

The emissions gap quantifies the difference between estimated GHG emissions in least-cost scenarios to meet specific temperature targets for the year 2030, and emissions associated to different policy scenarios. The United Nations Environment Programme annually quantifies the emissions gap and estimates a median gap of 13 (28) $GtCO_2e$ with respect to the 2 (1.5) degree Celsius target for fully implemented unconditional NDCs in August 2021 (United Nations Environment Programme, 2021). The gap increases by another 2 (3) $GtCO_2e$ when instead considering current climate policies, as their ambition levels are below that of submitted NDCs. The most recent adjustments of NDCs before the October 2021 have only slightly reduced the emissions gap, and annual emissions, which reduced in 2020 due to the Covid-19 pandemic, are expected to reach previous levels. There is furthermore an increasing number of countries adopting net-zero goals, which, if met, would bring at least the 2°C target in reach, by limiting the global average temperature increase to 2.0-2.4°C (Höhne et al., 2021).

However, closing the emissions gap and meeting increasingly ambitious climate targets requires that climate policies become more effective. Climate policies need to simultaneously reduce emissions, create low-carbon innovation, and lead to high shares of renewable electricity, in order to replace energy from fossil fuels with sustainable energy systems (Davis et al., 2018; Peters et al., 2020; Luderer et al., 2021). Costs for renewable electricity have strongly decreased during the last two decades (Kavlak et al., 2018; Steffen et al., 2020; IRENA, 2021), and experts, despite large uncertainties, expect further significant cost reductions (Wiser et al., 2016; Creutzig et al., 2017; Mauler et al., 2021; Wiser et al., 2021; Victoria et al., 2021; Luderer et al., 2021). Yet, increasing risks of price volatility and unexpected curtailment may hinder investment in countries with high shares of renewables (Egli, 2020), while higher financing costs are a major caveat for renewable investments in emerging economies (Steckel and Jakob, 2018; Ameli et al., 2021). Moreover, achieving the net-zero emissions goal creates new challenges, as technologies based on renewable electricity cannot replace all fossil fuels. Net-zero thus requires the innovation and upscaling of low-carbon technologies that also use other energy carriers, such as hydrogen or synthetic fuels, especially in industries that are difficult-to-decarbonize (Davis et al., 2018) (Section 1.3.4 discusses specific aspects of the political economy of hydrogen deployment). The next section discusses climate policy instruments, with a special emphasis on carbon pricing.

1.2 Climate policy instruments

Effective climate policy instruments need to be implemented rapidly in order to decrease GHG emissions and thus mitigate climate change. Yet, selecting an optimal mix of climate policies appears challenging when considering the variety of potential policy instruments. The effectiveness of climate policy instruments is, moreover, affected by several design options. This section provides an overview of theoretical and empirical insights on climate policy instruments, with a special focus on carbon pricing.

The following sections first introduce different types of climate policy instruments (1.2.1). Thereafter, I focus on carbon pricing as the most prominent market-based policy instrument by discussing its underlying theory (1.2.2), and the status quo of its implementation (1.2.3). Finally, I describe potential obstacles that may potentially constrain the effectiveness of carbon pricing policies (1.2.4), and then discuss in how far a carbon floor price as a design element may address these constraints (1.2.5).

1.2.1 Types of climate policy instruments

There is a long standing debate about the optimal selection of climate policy instruments. Market-based environmental policies are frequently proposed by economists as they theoretically achieve pollution reduction most efficiently, i.e. at lowest overall costs. The idea is to provide price incentives to market participants, such that they select the cheapest emission reduction option (Stavins, 2003). Depending on the classification, market-based instruments comprise carbon pricing (carbon taxes or cap-and-trade systems), emission reduction credits, feed-in-tariffs, and fossil fuel subsidy reductions. Conventional command-and-control approaches, most importantly, comprise specific technology- or performance-based standards. It is argued that these policy instruments would lead to higher costs, as their imposed emission reduction measures would neglect firm specific circumstances, and not provide incentives for innovation below fixed targets of pollution levels (Stavins, 2003).

Previous studies determining the optimal combination of climate policy instruments provide ambiguous results. The various findings show that the selection or mix between market-based and command-and-control policy instruments depends various conditions, which renders obtaining general takeaways challenging (Requate, 2005; Hepburn, 2006; Sterner and Coria, 2011). There is furthermore a lively discussion about the preferred market-based policy instrument (Aldy et al., 2010), as, for example, both general options of regulating emission via price or quantity instruments have different advantages and caveats (Weitzman, 1974; Hepburn, 2006). Yet, others find that the optimal policy portfolio consists of a policy mix (Fischer and Newell, 2008). That carbon pricing is at least an important component of a climate policy mix seems overall largely undisputed. The following section elaborates the theoretical background of carbon pricing as one highly important market-based climate policy instrument.

1.2.2 Carbon pricing theory

The idea of carbon pricing as one highly prominent market-based environmental policy instrument dates back to Arthur Cecil Pigou. Pigou first formulated the concept of positive and negative externalities, their impact on the economy, and measures to internalize these externalities by adjusting prices via Pigouvian taxes or subsidies (Pigou, 1920; Edenhofer et al., 2021). He thus formulated the general idea of imposing a price to the polluter (Pigouvian tax) that equals the societal damage of the pollutant (the externality).

Carbon pricing can be seen as a Pigouvian tax on carbon emissions. When a carbon price is introduced, polluters can assess whether their marginal abatement costs per unit of CO_2 is higher or lower than the carbon price, and hence decide to either reduce emissions, or to pay for their pollution (Schmalensee and Stavins, 2017). Polluters thus have the incentive to reduce pollution at lowest cost. In theory, carbon pricing at the same time leads to both short term emission reductions and innovation. Emission reductions either stem from substituting (fuel switch), or more efficiently using (efficiency) the pollutant. Subsidies on fossil fuels can be considered as negative carbon prices, as they, in direct opposition to carbon prices, even create an additional incentive to use fossil fuels, and to consume more of a good entailing negative externality. Types of subsidies comprise producer subsidies reducing input costs of fossil fuels, and consumer subsidies reducing market prices of consumer products. Reforming fossil fuel subsidies are considered a precondition, or a first step before introducing a positive price on carbon (UNDP, 2021). In the following, I focus on discussing specific aspects related to carbon pricing.

There are several general benefits of carbon pricing, and specific advantages over regulatory instruments. Paying for residual emissions incentivizes polluters to continuously innovate, as each additional unit of abatement would lead to further cost reductions, independent of the level of abatement achieved already. Carbon prices could furthermore affect the entire economy, whereas specific standards are bound to single applications that may not be among the cheapest abatement options, while firms with cheaper applications might manage to circumvent regulation (Aldy and Stavins, 2012). Adding to avoided climate damages, there are region-specific unilateral incentives for emission pricing that comprise higher public revenues, or co-benefits of cleaner air (Edenhofer et al., 2015). Government can use revenues from carbon pricing for multiple purposes, such as more directly steering innovation processes, or address political economy constraints (Section 6.2.1 more extensively discusses design options of revenue recycling schemes and describes previous empirical applications).

Carbon taxes and cap and trade systems are the most prominent and widely deployed types of carbon prices. Carbon taxes price carbon emissions at a level determined by the regulator, while cap and trade systems limit the quantity of carbon emissions for a specific time and region. For the latter, the carbon price emerges at the market where participants can trade certificates that represent one unit of carbon emissions. While both may in theory lead to equivalent emission reductions at identical prices, setting a carbon tax suffers from the difficulty of setting the price correctly to achieve the envisaged level of emission reductions, while cap and trade systems lead to price uncertainty among market participants (Weitzman, 1974). Ample literature discusses the advantages and disadvantages of both price and quantity instruments under specific conditions. Hybrid instruments build a combination of both, and are thus a potential option to address caveats of either one of both instrument types (Roberts and Spence, 1976; Pizer, 1997, 2002; Hepburn, 2006). The next section provides an overview of the implementation of carbon prices.

1.2.3 Implementation of carbon pricing

Governments increasingly adopt carbon pricing policies, but not at sufficient pace and stringency to meet climate targets. In 2021, carbon pricing schemes covered 21.5% of GHG emissions, with USD 53 bn of globally generated fiscal income in 2020 (The World Bank, 2021). In the same year, China introduced its national ETS, and thereby created the largest carbon market across the globe. However, although several countries recently increased their pricing level and trajectories, carbon prices are still low. Less than 4% of global emissions are covered by carbon prices above USD 40/tCO_2e, which is insufficient for achieving strong emission reductions (The World Bank, 2021).

Broader definitions of carbon prices may also comprise taxes or duties on goods with high carbon contents, without the price being explicitly related to carbon emissions. The OECD calculates such *effective carbon rates* for 44 OECD and G20 countries as the sum of emission permit prices, carbon taxes, and excise taxes on fuels (OECD, 2021). Effective carbon rates are highest for road transport, and usually low for the residential and commercial sector, and small industries. Countries having high effective carbon rates combine high prices on road transport, and higher prices on emissions from the residential and commercial sector. These countries often also participate, or are linked, to the European Union Emissions Trading System (EU ETS) that prices emissions from electricity generation and industry. The OECD also calculates a carbon pricing score, which evaluates the effective carbon rates against different benchmark carbon prices to quantify the effective coverage of carbon emissions by a price. For a benchmark price of EUR 60 per ton of CO_2, the 44 countries investigated jointly achieve a score of 19% in year 2018. It thus remains a carbon pricing gap of 81% (OECD, 2021).

Fossil fuel subsidies in 2020 still comprise USD 5.9 trillion, which amounts to 6.8 percent of the global GDP. This share is even expected to rise to 7.4 percent in 2025. The largest recipient of subsidies is the power generation sector. Almost haft of all energy subsidies occur in East Asia and the Pacific, while China is the single largest country subsidizing fossil fuels before the US, Russia, India, and the EU. Pricing fuels efficiently in 2025 alone would allow to keeping global warming below 1.5 degrees, while the net economic benefits would amount to 2.1 percent of the global GDP (Parry et al., 2021).

Implemented market-based policies thus significantly depart from optimal settings as proposed by economists, also with respect to other design elements than price and coverage (Stavins et al., 1997; Schmalensee and Stavins, 2017). For example, market-based-instruments have been mostly implemented as cap-and-trade systems with grandfathered permits, which significantly reduce the incentive to mitigate for polluters (Stavins et al., 1997). Implementing effective carbon pricing schemes with a wide sectoral coverage and stringent design elements thus remains an ongoing challenge.

1.2.4 Effectiveness of carbon pricing

Theoretical and practical aspects may influence the effectiveness of carbon prices in reducing emissions and triggering low-carbon innovation. These, most importantly, comprise the time-inconsistency problem leading to regulatory uncertainty and lacking credibility of climate policy (Kydland and Prescott, 1977; Helm et al., 2003; Koch et al., 2016; Nemet et al., 2017), myopia of market participants (Edenhofer et al., 2019), and dynamic inefficiencies (Salant, 2016; Edenhofer et al., 2019). Especially cap-and-trade systems face significant price uncertainty due to the prevailing possibility of future policy changes (Borenstein et al., 2019). More specifically, carbon prices may also lead to stranded assets (Rozenberg et al., 2020), especially under non-anticipated, time-inconsistent policies in response to political economy factors (Kalkuhl et al., 2020). They may also lack effectiveness if the supply of emission allowances exceeds the demand. Excess supply may result from lower economic activity, or additional national and international climate policies (Koch et al., 2014; Ellerman et al., 2016; Fuss et al., 2018a; Edenhofer et al., 2019).

Empirically assessing the effectiveness of carbon prices is challenging due to a different coverage and intensities of implemented policies, and the separation in their effect from other climate policies (Martin et al., 2016; Best et al., 2020). There has been a recent controversy about whether the ex-post evidence of carbon pricing points towards significant emission reductions (Andersson, 2019; Best et al., 2020; van den Bergh and Savin, 2021), or only show little effectiveness (Green, 2021; Lilliestam et al., 2021). Critiques claiming a low effectiveness base their views on review articles of ex-post studies that only find evidence for fuel switching, but no evidence for higher low-carbon investment (Lilliestam et al., 2021), and annual emission reductions of only 0-2% per year, and 0-1.5% within the EU ETS (Green, 2021). However, other empirical evidence shows that emissions decreased by 10% between 2005 and 2012 for the EU ETS, with a temporally changing impact from 6% less emissions in Phase I, to 15% in Phase II (Dechezleprêtre et al., 2018). Another review of empirical literature summarizes an effect of 3% in Phase I, but 10-26% during Phase II (Martin et al., 2016). The EU ETS has also contributed to low-carbon innovation, although policies directly targeting renewables, such as feed-in-tariffs, or renewable purchase obligations, have more effectively triggered innovation (Martin et al., 2016). Quantitative estimates based on firm patents show an increase of low-carbon innovation of regulated firms due to the EU ETS of 10% (Calel and Dechezleprêtre, 2016). More recent estimates, combining data on patents and spending on research and development (R&D), suggest that the EU ETS has lead to an increase of low-carbon patents and R&D spending of 20-30% (Calel, 2020). In addition to these debates about the effectiveness of carbon pricing policies, it is more generally discussed whether carbon pricing should be the guiding climate policy, or whether the transition to net-zero requires more fundamental changes of sociotechnical systems (Rosenbloom et al., 2020; Bergh and Botzen, 2020). Large parts of the critique on carbon prices rests on the low price levels of actually implemented carbon prices, and hinge on the assumption that higher prices are politically not feasible. Yet, the theoretical idea of a credible, economy-wide, and sufficiently high (or even increasing) carbon price being a potentially effective emission reduction policy remains largely uncontested.

Additional complementary policies may be needed to optimally addressing the above mentioned theoretical obstacles to carbon pricing, such as policy credibility, myopia, and dynamic inefficiency. These obstacles can be conceptualized as additional externalities leading to market failures and distortions (Edenhofer et al., 2021). For example, the Tinbergen rule describes that the optimal number of policies equals the number of targets (Tinbergen, 1952; del Rio and Howlett, 2013). Most importantly, it is argued that carbon pricing should be complemented by technology policies that subsidize innovations to internalize positive knowledge externalities, foster promising, but thus far, expensive technological solutions, and avoid a sustained fossil fuel lock-in (Unruh, 2000; Jaffe et al., 2005; Baranzini et al., 2017). Also informational failures and bounded rationality of households or businesses may require additional policies (Sanstad and Howarth, 1994; Baranzini et al., 2017). However, also specific design elements of carbon pricing policies can address some of the previously mentioned limitations (see next section).

1.2.5 Designing effective carbon prices

Specific design elements of carbon pricing schemes can at least partially offset the above mentioned limitations. Highly discussed design features for cap-and-trade systems are banking of allowances and hybrid systems combining elements of price and quantity instruments. It is argued that both would decrease the risk of price spikes or collapses, which would in turn lower system costs, decrease uncertainty of investors, and thereby foster low-carbon investment (Fell and Morgenstern, 2010; Grüll and Taschini, 2011; Fell et al., 2012b,a; Hasegawa and Salant, 2014; Schmalensee and Stavins, 2017). Next to price stability and certainty, it requires sufficiently high carbon prices to trigger low-carbon innovation and investment (Aghion et al., 2016).

Especially carbon price floors are suggested as reform options for cap-and-trade systems to correct for underlying market or regulatory distortions that prevent the price to achieve its cost-effective level (Wood and Jotzo, 2011; Flachsland et al., 2020). First, a carbon price floor may lead to intertemporal efficiency, if the price floor trajectory follows its cost-effective pathway, thereby offseting myopic behavior of investors (Fuss et al., 2018a). Second, a price floor may avoid higher abatement costs in the future that may arise in consequence of too little low-carbon investment resulting from low carbon prices. Such high future prices ultimately risk to undermine the political support for the entire cap-and-trade system (Edenhofer et al., 2019; Flachsland et al., 2020). Third, a carbon price floor at a sufficiently high level may increase long-term investment into low-carbon technologies by reducing investment uncertainty and signaling the political will to pursue effective climate policy (Burtraw et al., 2010; Flachsland et al., 2020). A carbon price floor is, for example, a design component of the Regional Greenhouse Gas Initiative (RGGI) in California and Quebec that entails an auction reserve price, or the carbon price floor in the United Kingdom (UK), that added the carbon price support, a domestic surcharge to the market price.

These discussions are further elaborated in Chapter 2 of this dissertation, which provides novel evidence on how different carbon price floor trajectories would affect low-carbon investments of firms. Moreover, Section 6.2.1 discusses additional mechanisms to address the time-inconsistency problem. The following section discusses how political economy factors affect the implementation of efficient and effective climate policies.

1.3 Political economy

Understanding the political economy around climate mitigation policies is crucial for their implementation. Political economy aspects comprise, among others, questions addressing the distribution of wealth, power and resources, or how the political environment including different institutions may influence policy outcomes (Sovacool et al., 2015; Jakob and Steckel, 2022). In the last decades, a steadily growing literature has addressed political economy challenges and potential solutions with respect to climate policy. This literature outlines how to implement policies leading to emission reductions, and how to trigger innovations required to achieve the net-zero emissions goal. Emerging economies, coming increasingly to the fore of climate policy ambitions, provide a special context.

The following sections provide a general introduction to the history of political economy and contemporary political economy approaches (1.3.1). Then I discuss insights and approaches of political economy in the field of climate policies (1.3.2). Based on this discussion, I describe two main challenges, namely the political economy of emission reductions focusing on emerging economies (1.3.3), and the political economy of low-carbon innovations focusing on hydrogen (1.3.4).

1.3.1 Historic and contemporary political economy

The field of political economy has undergone various changes throughout the last centuries. It has transformed from comprising aspects of virtually all social sciences, into various specific sub-disciplines, including modern economics (Milonakis and Fine, 2009). The classical political economy, represented by Adam Smith in the 18^{th} century, combined historical, social, philosophical, and psychological perspectives. His most important successors are David Ricardo and Karl Marx in the 19^{th} century. Ricardo introduced abstract thinking by deducting his theories from labour theory of value, while Marx's work remained more inductive and historical. In the early

20^{th} century, the *Methodenstreit* between the Austrian School around Carl Menger, and the German Historical School represented by Gustav Schmoller, resulted the marginalist revolution. The *Methodenstreit* formed the base for classical political economy turning into neoclassical economics, which has remained the dominant school of economic thought until today. In parallel, the separation of social sciences in general resulted in today's broad variety of disciplines, such as economics, political science, sociology, psychology, or anthropology, among others.

Neoclassical economics became and remains the dominant school of thought to analyze policy-relevant economic questions. A prominent definition on economics by Lionel Robbins (1932) describes the discipline as the following: "*Economics is the science which studies human behaviour as a relationship between ends and scarce means which have alternative uses.*" Strongly rooted in theory, neoclassical economics derives its insights from formal deductions based on axiomatic assumptions, such as rational behavior of agents, or methodological individualism, among others. The overall idea is to derive universal theories that are independent of cultures, nations and traditions. Historical circumstances thus play only a minor role, and institutions or politics have traditionally been neglected. Contemporary empirical research is dominated by statistical regression analyses, while more qualitative approaches are scant (Milonakis and Fine, 2009).

Meanwhile, contemporary political economy approaches emerged, building a bridge between economics and political science and other social sciences. Today, a wide array of topics and questions that had been addressed by political economists in the 18^{th} and 19^{th} centuries have subsequently been addressed by scholars from other disciplines. The oxford handbook of political economy (Weingast, 2008) compiles numerous articles on the political economy of various topics, such as voting and legislation, constitutional theory, social choice, public finance, macroeconomics, democracy and capitalism, non-democratic regimes, or international relations. Finding a widely accepted definition of political economy is challenging, given the breadth of researched topics and applied methods.

However, economists increasingly acknowledge that providing policy recommendations based on highly stylized assumptions without considering political economy aspects are an incomplete base for policy advice, and thus more of academic than of practical relevance. While economic theory allows to develop *first- or second-best* policies, it does not explain which policies are actually implemented and why, nor does it consider real-world constraints when developing policy recommendations in the first place. Understanding which policies may be feasible and why has thus become a key task, especially when considering timely and large scale problems, such as climate change mitigation, or surging inequality.

An increasing number of economists therefore aspire to provide policy advice that considers political economy constraints. Economists thus applied neoclassical economic theory to political economy questions and, for example, investigated topics such as optimal public spending and budget deficits (Alesina and Tabellini, 1988; Alesina and Perotti, 1995), or the credibility of promised policies during an election (Alesina, 1988). The role of institutions in affecting long-term growth and prosperity has as well gained prominence (e.g. Acemoglu et al., 2001; Acemoglu and Robinson, 2012), while others try to explain economic performance via diversity of the labor force, or cultural aspects (see Alesina, 2013, for overview). Along with thematic extensions, also methodologies have expanded, as randomized control trials, lab experiments, surveys, and ultimately historical research entered the field (Alesina, 2013). The next section narrows the focus from political economy in general, to the political economy of climate policies.

1.3.2 Political economy of climate policies

The implementation of theoretically effective climate policies may be hindered or affected by political economy factors. The political economy of climate policies has been addressed from a variety of perspectives and conceptual backgrounds (Trebilcock, 2014; Arent et al., 2017). The following paragraphs will briefly introduce several key concepts and strands of research, and then more specifically discuss the aspects of public acceptability and distributional impacts as particularly important political economy factors.

Economic methods and theories have been applied to a number of research questions related to political economy. For example, economic theory was enhanced to understand the interplay between the lobbying power and stranded assets (Kalkuhl et al., 2020; van der Ploeg and Rezai, 2020), lobbying and pollution taxes (Fredriksson, 1997), or the formation of environmental policy considering corruption and political stability (Fredriksson and Svensson, 2003). Empirical analyses based on time series assess the interplay between corruption and climate mitigation policies, and find that countries with a higher perceived corruption have weaker climate policies (Rafaty, 2018).

Scholars investigating sustainability transitions, defined as long-term, multi-dimensional, and fundamental transformation processes, analyze institutional, organizational, technical, social, and political aspects of sociotechnical systems that shift to more sustainable modes of production and consumption (Markard et al., 2012). The field applies various concepts and frameworks (Sovacool, 2014; Cherp et al., 2018). For example, the multi-level-perspective focuses on the struggle between emerging niches and established regimes (Geels, 2002), while more recent theoretical advancements also consider the upcoming cross sectoral and multidimensional transition to net-zero (Geels et al., 2017). The normative dimensions of equity and justice are addressed by the concepts of just transition, or the energy justice framework, which encompass questions related to energy access, energy poverty, affected workers, the well being of future generations, and distributional impacts (Newell and Mulvaney, 2013; Sovacool et al., 2016; Healy and Barry, 2017; McCauley and Heffron, 2018).

Research based on empirical case studies has tried to understand why effective climate policies are implemented, and under which conditions they remain stable. They find that the stability and effectiveness of environmental regulation depend on the distribution of costs and benefits between the regulated actors, and the public (Oye and Maxwell, 1994). The authors distinguish between two stylized settings. In *Stiglerian* settings, the regulated actors benefit from regulation, for example due to subsidies or a monopolistic advantage, while costs are dispersed over many. A combination of self-interests of the regulated, and environmental goals of the public result in regulatory stability. In *Olsonian* settings, regulatory benefits are diffused, while regulatory costs are concentrated, resulting in few losers mobilizing against regulation, while beneficiaries lack sufficient motivation to support the regulation. *Olsonian* settings therefore suffer from regulatory instability. The stable *Stiglerian* settings, however, risk lower public welfare and inequitable market access. Compensating losers may be one solution to overcome resistance in *Olsonian* settings. Independent of the setting, regulation tends to be most effective when it offers benefits for the regulated, either by chance, or by design.

Understanding goals and strategies of different actor groups with special interests are thus important aspects of the political economy. The literature provides a variety of frameworks to understand actors in transition processes (Wittmayer et al., 2017). The actors, objectives, context (AOC) framework (Jakob et al., 2020a) assumes that political actors adopt climate policies, but that they are influenced by societal actors, and guided by different societal objectives. I use this framework in Chapter 3 and 4 of this dissertation to compared the political economy of coal across multiple countries, and specifically in India. Different groups of societal actors may use different strategies and channels to influence climate policy making. For example, corporate political strategies used by privately owned companies can be categorized under the information strategy, the financial incentive strategy, or the constituency building strategy (Hillman and Hitt, 1999). State owned companies may yet use other strategies, as they are already by definition close to policymakers, making revolving door policies and provision of information an envisaged status quo (Dorband et al., 2020). Voters can exert power over policymakers during elections, while NGOs may create public support for climate policies via public events, or participation in discourses.

Public support and distributional impacts are major determinants to gain the support of voters, and thus for the political feasibility of climate policies, including carbon pricing. Recent review articles on public support for climate policies cluster the key factors in the categories of i) social-psychological factors and climate change perception, ii) the perception of climate policy and its design, and iii) other contextual factors (Drews and van den Bergh, 2016), but also emphasize the importance of distributional effects (Maestre-Andrés et al., 2019). Differences in climate policy mixes between countries are explained by the public opinion, distributional effects for the energy industry, and the government's institutional capacity (Hughes and Urpelainen, 2015). Focusing on the feasibility of carbon pricing policies, studies find that distributional impacts on households are among key political economy factors (Baranzini et al., 2017). Yet, distributional impacts of carbon pricing on households differ by country income level, and are rather progressive in low-income countries, and more progressive in high-income countries (Dorband et al., 2019; Ohlendorf et al., 2021). Guidelines on how to alter public oppositions to enhance the acceptability of carbon prices see one key role in recycling revenues (Klenert et al., 2018; Carattini et al., 2018). In practice, revenues are mostly used for tax cuts, or direct rebates for corporations or individuals, but also as subsidies for energy efficiency or renewable energies, or to increase the state's general income (Carl and Fedor, 2016). In Section 6.2.1, I will discuss how using revenues may effectively increase the political feasibility of implementing carbon pricing policies.

Section 1.2 argued that emission reductions and low-carbon innovation requires effective climate policies. This section, thus far, introduced the field of political economy, and provided first overview of political economy factors affecting the implementation of climate policies and carbon pricing schemes. The following two parts outline two specific challenges, namely how political economy factors affect emission reductions (Section 1.3.3), and low-carbon innovations (Section 1.3.4).

1.3.3 Challenge one: Political economy of emission reductions

Political economy factors can delay the implementation of effective climate policies that are needed to initiate a rapid phase-out of carbon emitting fossil fuels. To decarbonize the electricity generation, a coal phase-out is most crucial, while renewable energies need to be phased-in simultaneously. Understanding drivers of the recent coal deployment and barriers to renewable deployment requires a deeper assessment of the political economy of both power sources. The following paragraphs discuss the history of modern coal use, political economy factors affecting coal and renewable deployment, and outline key challenges hindering rapid coal phase-outs by especially focusing on emerging economies.

The modern coal use begins with the industrialization of the UK in the 18^{th} century. Its higher energy density, compared to the previously used wood, made coal become an essential element for energy generation in the UK and across large parts of Europe (Wrigley, 2013). Since then, coal was increasingly used to produce iron and steel, to provide heating, and to fuel steam engines (Thurber, 2019; Fernihough and O'Rourke, 2021). In addition to fostering the industrialization, coal also contributed to growth of cities adjacent to coal mines; due to its high transport costs, small villages nearby coal reservoirs all across Europe transformed to industrial centers (Fernihough and O'Rourke, 2021). With the onset of the electrification in the late 19^{th} century, power generation became another application for coal. In the year 1970, coal already contributed about one third of the global electricity supply. With the oil crises in the 1970s triggering a demand for a higher energy autonomy, its share increased to more than 40% in the 2000s (World Bank, 2021). Coal as a cheap, abundant, and increasingly internationally traded energy source, has by now become the globally dominating fuel for power generation (Thurber and Morse, 2015).

The economic impacts of regional coal infrastructure deployment may have implications for the political economy of prospective coal-phase outs. The extraction of natural resources like coal increases the local demand for labor and induces potential spillover effects in other economic sectors (Marchand and Weber, 2018). The resulting socio-economic impacts can be conceptualized as i) primary impacts, such as employment and income increases, ii) secondary impacts, such as higher demand of goods and services, and new indirect employment, but also potentially less competitive tradable goods due to higher wage levels, and several iii) tertiary impacts, such as new other infrastructure, higher housing prices, or changes in the demographic profile (Measham et al., 2016). Phasing-out coal thus leads to regional job losses, which can affect the voting behavior, as for example in regions of the United States, where the share of Republican votes in the 2012 and 2016 elections increased significantly (Egli et al., 2020). In addition to unemployment, a decline of coal may lead to reduced tax incomes, which can put high pressure on regional governments (Jolley et al., 2019; Morris et al., 2019). Regional coal dependencies may thus lead vested interests of different stakeholders, which need to be considered when developing coal phase-out strategies (Jakob et al., 2020b).

In analogy to the role of coal in the historic European industrialization, coal is now considered a crucial component of the industrial development in emerging economies (Thurber and Morse, 2015). Since 2010, investments to coal-fired power plants focused especially on emerging and developing countries, comprising most importantly China and India, but also several Asian and African countries (Steckel et al., 2015, 2020). Economic benefits alone cannot explain this surge in coal, and even the proclaimed positive impacts on economic growth and labour demand have been contested.[2] The earlier mentioned adverse health and local environmental impacts (Rauner et al., 2020), and increasingly cheap renewables (Nemet, 2019), are further reasons to restrain from deploying further coal-fired power plants. Understanding factors driving the recent deployment of coal, and moreover, analyzing looming challenges for upcoming coal phase-outs in emerging economies, are thus key.

Reviewing experience from industrialized countries that started to decarbonize their energy systems may build a suitable starting point. A recent article that synthesizes insights from studies on previous coal transitions shows that main drivers for coal phase-outs comprise high production costs of coal mining and power generation, the availability of affordable renewable energy sources, air pollution causing health problems, an old age of power plants, and financial aspects (Diluiso et al., 2021). Main barriers are regional economic dependencies of coal producing regions, the fossil fuel industry, miner unions, missing climate policies, fossil fuel subsidies, cheap coal prices, high renewable prices, and finally, obtaining the required capital investment (Diluiso et al., 2021). Moreover, people living in coal-dependent regions with a long tradition of using coal may in turn oppose coal phase-outs to preserve their local identity. However, insights from previous coal transitions may be only partially applicable to ongoing challenges; decarbonization has rarely been the main, nor the only reason for a declining coal use, and challenges may differ for emerging economies. A systematic literature review on drivers and barriers of sustainability transitions in developing countries shows large differences to developed countries, making comparisons challenging (Wieczorek, 2018).

In many emerging economies, governments have particularly strong roles in the energy sector, and thus also over policies affecting coal mining and power plant deployment. Governments often control the markets via publicly set prices, or the direct ownership of state-owned enterprises (Thurber and Morse, 2015). In democracies, this creates incentives for governments to use coal strategically for their own benefit. For example, in India electricity theft is more tolerated in the advent of elections, while keeping electricity prices low is a major objective of any government (Min and Golden, 2014; Mahadevan, 2021). Due to weaker social security systems in emerging economies, losing a job, or being unable to pay for electricity, can threaten the existence of affected people, which further increases the responsibility of, and pressure for policymakers.

Long established coal industries and resulting vested interests pose another challenge, also for emerging economies. In emerging economies that mine coal, coal is often perceived of as an important source of employment, and as a cheap and reliable energy source for consumers. In these countries, coal also generates large revenues for governments and corporations (Spencer et al., 2018). Vested interests may

[2]Interestingly, it is not clear in how far coal today actually contributes to economic growth. Coal has indeed provided massive employment opportunities in the past, and there is evidence that the US coal boom in the 1980s has lead to spillovers to other sectors (Black et al., 2005). However, in the last decades and centuries, labor demand for coal has generally reduced due to technological progress (Betz et al., 2015), and the idea that extracting natural resources would unambiguously increase labor demand and long-term economic growth, has at least been contested (Ploeg, 2011; Marchand and Weber, 2018).

span the entire value chain from coal mining, transport and power generation. For example, the two countries with the highest annual coal consumption, China and India, both have large mining reservoirs, while in both countries the railway system and coal are strongly interlinked (Jakob and Steckel, 2022). Such linkages and domestic dependencies require consideration when designing coal phase-out policies.

Ample research addresses the political economy of energy transitions from fossil fuels to renewable energies. Experience from EU countries shows that RE deployment is negatively affected by lobbying of the manufacturing industry, while it is fostered by governments with left-wing political orientation and the quality of the government (Cadoret and Padovano, 2016). Further insights stem from numerous country case studies including some for emerging economies, such as South Africa and Brazil (Hochstetler, 2021), or Mozambique and South Africa (Power et al., 2016). For example, the political economy of the energy transition in South Africa is characterized by extremely powerful incumbents with large levers over policymakers, and lock-ins arising from attempts to achieve energy independence (Baker et al., 2014). Also the structure of energy markets is unfavorable for renewables in some countries. For example, grid operators in India sometimes curtail renewables in spite of a renewable purchase obligation, as low consumer prices set by the government would be insufficient to pay the costs of producers, leading to excess energy generation and black-outs at the same time (Dubash et al., 2018).

Despite these challenges, there are few recent developments counteracting the coal deployment. There is, for example, an increasing public awareness of local environmental damages, especially air pollution. This also applies for India and China, where growing middle classes start resisting against local pollution. Formerly coal-dependent countries, such as the UK or Germany, are gradually decreasing their coal use, and an increasing number of countries have adopted coal phase-out plans. In 2021, also China declared to stop financing coal-fired power plants abroad. Moreover, during the Conference of the Parties (COP) 26 in Glasgow in 2021, more than 40 countries, including several coal-dependent emerging economies like Indonesia and Vietnam, pledged to abstain from building new coal-fired power plants, and to eventually phase-out coal under certain conditions (New York Times, 2021). However, China and India also last minute managed to adjust the wording of the Glasgow Climate Pact, the first treaty of a COP that specifically considers coal, from envisaging a *coal phase-out*, to a *coal phase-down*, as a phase-out would unfairly damage their economic growth (Reuters, 2021). Considering these ambiguous signals and the previously discussed driving forces for coal, it remains uncertain whether, or when pledges to stop coal finance will be actually fulfilled.

In Section 1.1.2 I have argued that future emissions may be decisively affected by deployment of coal-fired power plants in emerging economies, and in this Chapter that coal deployment is guided by specific political economy factors, including certain objectives related to economic benefits, and resistance by incumbent actors in the energy sector. Chapter 3 of this dissertation shows that energy experts consider economic growth, energy system stability, and cheap electricity prices main objectives in many emerging countries for building coal-fired power plants, while environmental objectives, such as climate change mitigation, or local air pollution, are considered less relevant. There thus seems to be a perceived trade-off between economic interests and environmental goals. Section 6.2.2 will discuss ideas on how to align objectives of emerging economies currently related to coal with renewable electricity alternatives. Section 6.2.3 discusses how resistance of incumbents can be overcome to achieve phase-outs of unsustainable technologies.

1.3.4 Challenge two: Political economy of hydrogen deployment

This section explores how meeting the net-zero emissions goal and the upcoming transition to low-carbon technologies may threaten incumbent business models, and how this novel setting creates special interests for incumbents to influence policy decisions. The remainder first elaborates on the implications of transitioning to economies with net-zero carbon emissions, then explains the potential role of hydrogen to achieve this goal, and finally describes challenges arising around the political economy of hydrogen deployment.

There are several complementary approaches to achieve the net-zero emissions goal. Further significant emission reductions via established methods comprise the continued deployment of renewable energies to decarbonize the power sector, and efficiency gains across all other sectors. However, to achieve net-zero emissions, it ultimately requires substituting carbon emitting technologies from all sectors with low-carbon technologies, or to remove residual carbon emissions from the atmosphere (DeAngelo et al., 2021).[3] Residual emissions can theoretically be removed by using negative emission technologies, such as direct air capture (Gambhir and Tavoni, 2019; Breyer et al., 2019), or bioenergy with carbon capture and storage (Fuss et al., 2014, 2018b). These technologies are likely to become increasingly relevant, although their role for climate change mitigation is subject to the aspired climate target (Fuss et al., 2018b; Minx et al., 2018; Nemet et al., 2018). Other mitigation pathways based on high energy demand reductions could completely avoid using negative emission technologies (Grubler et al., 2018). The International Energy Agency (IEA) envisages a radical technological transformation to achieve the net-zero emissions goal as based on the electrification of end-use sectors, carbon capture, utilisation and storage, hydrogen and synthetic fuels, and bioenergy (IEA, 2021a). In the following, I exclusively focus on challenges related to the substitution of carbon emitting technologies with low-carbon technologies, while the other topics are beyond the scope of this dissertation.

Substituting carbon emitting technologies will require the innovation and upscaling of low-carbon technologies across all economic sectors (Davis et al., 2018). During the last decades, discussions focused especially on the decarbonization of the power sector, where renewable energies have already successfully replaced parts of the previously fossil fuel based power capacity. Since recently the focus has broadened, as an increasing number of countries has pledged to achieve net-zero until the mid of the century (Höhne et al., 2021; The World Bank, 2021). The current political debate around climate change mitigation therefore now includes the remaining economic sectors, such as heating, transport, agriculture, and industry. In some sectors, new low-carbon technologies already replace selected fossil fuel based technologies; battery electric vehicles increase their market share over combustion engine cars in the transport sector, and heat-pumps increasingly replace oil and gas heaters. To replace fossil fuels that have thus far been used for many other

[3] For comprehensiveness, there is also the highly contested option to reduce the greenhouse gas effect by reducing the sun radiation via geoengineering (Biermann et al., 2022).

applications, such as the steel or the chemical industry, will, however, require innovation of new low-carbon technologies (Stern and Valero, 2021).

The innovation of low-carbon energy technologies can be conceptualized by different stages that are influenced by public policies. Gallagher et al. (2012) take a systemic perspective, and describe the *Energy Technology Innovation System* as comprising of five stages, namely research, development, demonstration, market formation, and diffusion that influence each other via feedbacks. Such innovation systems would be shaped by actors, networks, and institutions, that operate within a wider context outside the innovation system, and are characterized by interdependence, uncertainty, complexity, and inertia. Public policies take a key role. Consistent public policies that both support the technology-push and demand-pull are considered important to scale-up innovations to reduce costs, and to amplify private sector engagement by stabilizing policy expectations (see Section 6.2.1 for further discussion about time-inconsistent policies). Yet, the authors also highlight that the public sector may need to overcome potential resistance by actors with vested interests, and barriers arising from incumbent energy technology lock-ins or path dependencies (Unruh, 2000).

Innovation systems around low-carbon technologies required for net-zero are subject to a particularly high complexity, and also the roles of affected incumbent actors may differ from previous transitions. In contrast to previous energy transitions, the net-zero transition affects multiple sectors and technologies at once, while different low-carbon technologies compete against each other. This multi-sector characteristic increases the number of involved actors compared to single-sector transitions, and thus increases the diversity of backgrounds and interests (see conceptual framework in Chapter 5). Another major difference is that many incumbent actors have now at least publicly accepted the net-zero emissions goal, which alters their previous role from resisting transitions, towards shaping them in their interests. The following paragraphs focus on hydrogen and electricity based low-carbon innovations, by first describing the role of hydrogen in net-zero energy systems, then discussing potential climate implications of hydrogen deployment, and finally outlining consequences for incumbent actors and policymakers.

Low-carbon energy carriers, such as hydrogen or synthetic fuels, are considered as the only solutions for several difficult-to-decarbonize applications, and as potential solutions for many further applications, where they compete with renewable electricity. Technologically, the decarbonization of most applications is possible with different low-carbon energy carriers (Davis et al., 2018). Although hydrogen and synthetic fuels are from an energy efficiency perspective generally inferior to direct electrification (Ueckerdt et al., 2021), an economically optimal choice may consider additional relevant properties of both energy carriers. Hydrogen and synthetic fuels have several advantages, such as a high energy density, the potential to store and transport them, and their combustibility, which may enable the decarbonization of technologies that are difficult-to-decarbonize otherwise (Ueckerdt et al., 2021). This especially applies to processes in different industrial sectors, such as the steel, cement or the chemical industry, but also to aviation and shipping. Moreover, hydrogen may potentially support long-term energy storage and grid balancing in power systems with high shares of renewable energies.

Whether hydrogen is actually a low-carbon energy carrier and thus effectively contributes to net-zero, however, depends on the production method. The different production methods are commonly denoted via colors. Hydrogen can be separated from water molecules by using electricity. Using renewable electricity creates carbon free *green hydrogen*. Another option is to separate hydrogen from hydrocarbons contained in fossil fuels. The most discussed non-green option is *blue hydrogen*, which is generated from natural gas, while the carbon is envisaged to be stored underground using carbon capture and storage. Producing blue hydrogen may lead to substantial carbon emissions, although specific estimates depend on assumptions, and whether fugitive methane emissions are considered (Howarth and Jacobson, 2021; Rosenow and Lowes, 2021; Longden et al., 2022). The various other production methods of hydrogen differ with respect to the type of electricity used for electrolysis, the used fossil fuel, and the specific production technique. Producing synthetic fuels from hydrogen requires additional process steps, which leads to further energy losses.

Thus far, low-carbon hydrogen is still an emerging energy carrier, but with an increasing momentum.[4] In 2021, 17 countries had already adopted hydrogen strategies, while another 20 strategies are under development (IEA, 2021b). Yet, these strategies differ by the considered production methods for hydrogen. For example, Germany promotes exclusively green hydrogen, the European Union also promotes blue hydrogen, while Australia, among other efforts, envisages to export lignite-based *brown hydrogen* to Japan (Australian Government, 2018). The emergence of a global hydrogen economy within the next decades is thus very likely, but its scale, and its associated carbon emissions are yet undecided, and are affected by political decisions.

The transition to net-zero will substantially affect incumbents from a broad range of industrial sectors. We know that the previous deployment of low-carbon technologies in the power sector has already significantly disrupted existing business models of fossil fuel incumbents (Kungl and Geels, 2018). The same may apply to incumbents from other sectors using carbon-emitting production processes, such as the production of steel or cement, or producing carbon-emitting end-use technologies, such as ships and airplanes. The impact on individual incumbents depends on whether they can adjust their processes and products. Whether this is feasible, depends on its compatibility with the deployed low-carbon technology, or potential public support. Some incumbents will successfully manage to adopt low-carbon technologies, while those with less flexible business models are under severe threat.

There are notable differences in the compatibility with hydrogen or electricity between sectors, individual applications within sectors, and also individual companies. For example, especially the gas and heat industry could benefit from a widespread use of hydrogen, as this would maintain parts of their transmission and distribution infrastructure for natural gas, or provide the opportunity to build up new infrastructure for hydrogen. Using blue hydrogen in particular could also save the value of natural gas assets owned by vertically integrated companies. Yet, a further accelerating dissemination of electricity based heat-pumps would make conventional heating systems and larger parts of the existing infrastructure obsolete. In the UK, gas incumbents have already tried to establish a narrative around *green gas* as the preferable solution for decarbonization compared to electricity (Lowes

[4]Hydrogen has already been used in the fertilizer industry and for oil refineries at industrial scale. However, hydrogen used in these sectors has been produced using carbon-emitting fossil fuels.

et al., 2020). Another example are far more heterogeneous positions of incumbents in the transport sector. For long-distance aviation and shipping, using hydrogen or synthetic fuels are widely considered as the only options. However, the preferred low-carbon energy carrier is unclear for trucks and buses, while for private cars, since recently, an increasing majority exclusively focuses on battery electric vehicles. These examples illustrate the diversity and complexity between the preferred low-carbon energy carrier and associated technologies in different sectors. Chapter 5 provides more insights on sectoral differences in the discourse around hydrogen for the case of Germany.

The high impact of the net-zero transition on incumbents entails a special challenge for policymakers. The large scale adjustments of production facilities, end-use technologies, and infrastructures will require significant public financial support. In addition, there is large uncertainty about which net-zero technologies would be optimal for the different applications (Ford and Hardy, 2020; Bistline and Blanford, 2021; Azevedo et al., 2021). The combination of incumbent business models being under threat, and uncertainties about optimal net-zero pathways, provide interests and possibilities for incumbents to influence decision-makers. With respect to hydrogen, this implies advocating the production of blue or green hydrogen methods, hydrogen-based end-use technologies as well as transport and distribution infrastructure. Successful influence of incumbents with special interests risks sub-optimal investment and public funding, and thus to create path dependencies and the lock-ins. Section 6.2.4 will further elaborate the novelty of the challenge with a focus on the discourse and discuss how regulators may enhance their decision-making under high uncertainty and influence of incumbents.

1.4 Objective, outline, research question

Limiting global warming to well below 2°C, and ideally 1.5°C above pre-industrial levels, requires climate mitigation policies that effectively reduce emissions and foster low-carbon innovation. Implementing effective climate policies requires considering political economy factors.

This dissertation assesses the interplay between the design of effective climate mitigation policies, and the political economy around emission reductions and low-carbon innovation. It specifically analyzes i) how climate policies can be designed more effectively, and ii) the political economy around the decarbonization of the power sector, as well as emerging low-carbon innovations. The overarching goal is to understand why climate policies are not implemented with sufficient pace and stringency, and how this could be changed. The main research questions addressed in this dissertation are the following:

1. What would be the impact of different carbon price floor trajectories in the EU ETS on investments of German energy companies?
2. Which political economy factors systematically contribute to the sustained deployment of coal-fired power plants in eight major coal countries?
3. Which political economy factors are specific to a sustained deployment of coal-fired power plants in India as an emerging economy?

4. Which narratives are communicated by different actors in the emerging German discourse around hydrogen, and why?

The following chapters 2-5 contribute to answering these research questions.

Chapter 2 investigates the interplay between different carbon price floor scenarios and low-carbon investment of firms. Using novel survey data of German energy companies, it provides ex-ante evidence on how two price floor trajectories in the EU ETS would affect the size and portfolio of firm investments. The findings of the chapter contribute to the debate on how carbon pricing schemes can effectively trigger innovation and investment, by complementing insights from ex-post studies.

Chapter 3 assesses the interplay between political economy factors and policies affecting the deployment of new coal-fired power plants. Based on online survey data of energy experts, the chapter compares how contextual factors, societal objectives, and actors in eight major coal countries affect coal-related policies, and which strategies and arguments are used by pro-coal actors. The findings may inform domestic and international policymakers when discussing strategies and policies to initiate coal phase-outs.

Chapter 4 analyzes in-depth the political economy of the power sector in India. Building on semi-structured interviews, it enhances the understanding of mechanisms and drivers of a continued coal deployment, and sheds light on looming challenges of an eventual coal-phase out. The chapter adds new insights to the extant literature on energy politics in India. Within this dissertation, this case study approach complements the comparative analysis from the previous chapter, by analyzing the political economy of coal in one specific emerging economy and major coal country in detail.

Chapter 5 studies the discourse around hydrogen as an important low-carbon energy carrier for achieving the net-zero emissions target. Using newspaper articles, the chapter shows which narratives are used by different actors in the German hydrogen discourse. A discourse network analysis focuses on three emerging conflicts about its use, production method, and imports, while a new framework for multi-sector transitions guides the interpretation of the findings. The chapter thus combines a novel empirical topic with a new conceptual lens. Policymakers may obtain a better understanding and hence more critically evaluate narratives formulated by especially incumbent actors on the emerging hydrogen economy.

The final Chapter 6 synthesizes and discusses the main findings. It first embeds the outcomes of each chapter into a broader context, and secondly discusses selected findings and future challenges. It then more specifically i) elaborates on how to design effective climate policy mixes, ii) discusses under which conditions renewable energies may replace coal in emerging economies, iii) develops strategies how to overcome resistance of fossil fuel incumbents against emission reductions, and iv) outlines ways to reduce the influence of incumbents on upcoming net-zero transitions.

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Chapter 2

Carbon Price Floors and Low-Carbon Investment: A Survey of German Firms

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Investment decisions

ABSTRACT

Introducing a price floor in emissions trading schemes (ETS) theoretically stabilizes expectations on future carbon prices and thus fosters low-carbon investment. Yet, ex post evidence on high carbon prices is scant and the relevance of carbon pricing for investment decisions is frequently contested. We provide empirical ex ante evidence on how a price floor in the EU ETS would impact the size and portfolio of energy firms' investments. Analyzing survey responses of high-level managers in 113 German energy and industry companies, we find that the level of the price floor is crucial. A low price floor trajectory only provides insurance against downward price fluctuations and would leave investments largely unchanged except for industries receiving electricity price compensation, which reduce their investments. A high floor, significantly increasing the price level beyond current expectations, leads to higher investment by the majority of firms, especially by green firms, while investment in fossil energy would partially be abolished. Our studies implies that price floors can be important design components of ETS. However, policymakers need to ensure that they are at sufficiently high levels to affect investment decisions in a meaningful way.

1. Introduction

Pricing carbon creates a disincentive to the use of carbon-emitting technologies and stimulates investment and research and development efforts in low-carbon technologies (Andersson, 2019; Best et al., 2020). However, many policy makers and analysts doubt that carbon pricing is actually relevant to the investment decisions companies face (Grubb et al., 2013). For example, the EU Emissions Trading Scheme (EU ETS), thus far the world's largest of such schemes, has been only modestly effective in triggering investment in low-carbon innovation (Calel and Dechezleprêtre, 2016; Ellerman et al., 2016). One important reason for this lack of efficacy has been the low price of European Emission Allowances (EUA), decreasing from EUR 30 to around EUR 15 during the 2008–09 financial crisis and ranging between EUR 5–10 from 2012 to 2017 (Sandbag, 2019). After a major reform in 2017, the EUA price has increased to around EUR 25, with significant volatility above and below this value until late 2020. Following the onset of the COVID-19 pandemic, the EUA price dropped by almost EUR 10, then returned to previous levels, and ultimately increased to more than EUR 90 in early 2022. Despite recently high price levels, there is no guarantee for investors that prices persist at high levels, especially when considering the historic price volatility, which makes low-carbon investment risky and thus generally discourages it.

One proposed policy innovation, a carbon price floor, would make price expectations more reliable by truncating downside price risk. This would generally raise prices in expectation, and thus create stronger incentives for low-carbon investment (Wood and Jotzo, 2011). While a price floor may be politically adjusted and might also suffer from a lack of policy commitment, it would gradually increase price certainty. In this paper, we aim to improve the understanding of how a carbon price floor serves (i) as insurance against downward price risk along the expected price path and (ii) as a device to increase the level of the carbon price trajectory, which would affect investment decisions for companies from various sectors. We focus specifically on the uncertainty in expected carbon prices and assess the effectiveness of two different price floor trajectories in fostering low-carbon investment, one along existing price expectations and another at a higher level.

Theoretically, low-carbon investment depends, among other things, on expectations of future prices, which themselves depend on the credibility of the broader set of political, institutional, and policy

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configurations affecting those prices (Nemet et al., 2017b). For example, the well-established time-inconsistency problem illustrates how policy makers cannot ensure that policies will remain unchanged, even under strong assumptions, because optimal policies change over time (Kydland and Prescott, 1977). Investment in energy equipment is particularly vulnerable to time-inconsistency because it is typically irreversible (Bernanke, 1983) and long-lived (Helm et al., 2003). Furthermore, policymakers may have near-term political incentives to adjust the policy, for example, in the case of the EU ETS by adjusting the emissions cap (Habermacher and Lehmann, 2020). The resulting commitment problem not only leads to investment uncertainty, but can also render a Pigouvian instrument ineffective (Kalkuhl et al., 2020).

A price floor in the EU ETS may effectively foster low-carbon investment by addressing multiple underlying sources for previously low and volatile EUA prices. For the EU ETS, literature has identified three main reasons why allowance prices were low in the 2012–18 period (Flachsland et al., 2020): (i) low demand for allowances due to the European recession, the Clean Development Mechanism, and additional national energy policies (Ellerman et al., 2016; Fuss et al., 2018); (ii) doubt about the level of policy ambition and concerns about the politics affecting allowance supply (Koch et al., 2016; Salant, 2016); and (iii) myopic investor behavior (Kollenberg and Taschini, 2019). While some observers associate the 2018–19 EUA price increase with the 2018 EU ETS reform which, among other goals, attempted to reduce the supply of EUAs, it remains unlikely that the reform addressed all previously described problems. Some even argue that the EU ETS might face an investment bubble (Friedrich et al., 2020). A carbon price floor has the potential to stabilize price expectations in the ETS (Abrell and Rausch, 2017) and hence support long-term investment certainty (Schmalensee and Stavins, 2017) by addressing potentially dynamically inefficient carbon prices (Salant, 2016; Fuss et al., 2018) and, in addition, strengthening governments' commitments to decarbonization targets.

Practical experience with ETS over three decades shows that cost-effectively meeting emission targets is generally feasible, but implementation details and design elements, such as price floors or price collars, are highly relevant (Borenstein et al., 2019; Kuusela and Lintunen, 2020; Hintermayer, 2020). Carbon price floors are, for example, established in the Regional Greenhouse Gas Initiative (RGGI) that covers several US states and applies a minimum price to its auctions (Burtraw et al., 2018). They also exist in the California ETS, and in the German ETS for transport and heating sectors. In the EU context, a carbon price floor in the power sector was, for example, introduced in the United Kingdom in 2013 to foster low-carbon electricity generation. Early assessments indicate that it significantly contributed to reducing the share of coal in the UK electricity mix (Abrell et al., 2019; Leroutier, 2022) and increased low-carbon patenting and research expenditures (Calel, 2020). However, its impact on low-carbon investment has presumably been hampered by regulatory uncertainty beyond 2020 (Hirst, 2018). Several EU member states are considering implementing a price floor in the EU ETS. Yet, the EUA price floor design and price levels that would be required to foster low-carbon investments remain unclear.

This paper empirically assesses how a carbon price floor in the EU ETS would affect investment decisions of German energy companies, using the responses from a survey conducted in late 2018 and early 2019. We surveyed firms in Germany as the country has the highest absolute CO_2 emissions in Europe and the sixth largest per capita emissions (German Environment Agency, 2019). The sample covers 33 percent of verified German CO_2 emissions covered by the EU ETS in 2017. The survey results include information from 113 electricity and energy intensive companies on: (i) expectations about climate policy and carbon prices for 2020, 2030 and 2050; (ii) current (2018/19) investment patterns; and (iii) the impact of a hypothetical low and high EUA price floor trajectory on investment levels and portfolios.[1] We employ an ex-ante approach based on stated preferences due to (i) scant availability of ex-post data, (ii) the potential to elicit impacts of price floors higher than those which are currently implemented, (iii) and to circumvent methodological challenges of ex-post analyses in constructing a plausible counterfactual scenario (limitations to our approach are discussed in Section 4.3).

We find that a low carbon price floor, i.e. at average expected carbon price trajectory levels, has the effect of adding insurance against downward price risk and has limited impact on investment decisions: most firms maintain their investment level and portfolio unchanged, except for industry companies receiving compensation for indirect carbon costs embedded in the electricity price. Such companies are likely to reduce their investment level and thus abolish or reallocate fossil investment. In the high floor case, where the price floor has the additional effect of increasing the expected carbon price trajectory, the majority of respondents indicated that low-carbon investments would increase, thus confirming the relevance of carbon pricing for investment decisions. In this case, almost all green electricity companies would increase their investment level and diversify their portfolio. In contrast, industry companies receiving an electricity price compensation are even more likely to decrease their investment. Compared to a low price floor, a higher price floor trajectory has the effect of raising the investment of companies with more uncertain carbon price expectations.

We highlight two implications for policy. First, that green electricity companies would only moderately respond to a low price floor trajectory is in line with previous findings for the electricity sector, showing only weak links between the current ETS prices and RE deployment. In the literature some have argued that feed-in tariffs are a more adequate policy instrument to trigger RE investments (Polzin et al., 2019). However, we show that sufficiently high expected carbon prices may be equally successful. Second, that investment by energy intensive companies receiving an electricity price compensation would decrease with a low price floor, may be the consequence of (i) abolished fossil investment or (ii) re-allocated investment outside of Germany. While decreased total fossil investment as an outcome of the price floor might be expected, the possibility of carbon leakage needs to be considered by policy makers when introducing a price floor.

The remainder of this paper is structured as follows: Section 2 formally illustrates the mechanisms of a price floor and derives hypotheses about the impact of a carbon price floor on the investment level. Section 3 describes our data and the responses to our survey. Subsequently, we elaborate our empirical analysis approach. Section 4 analyzes and interprets our survey findings while Section 5 discusses the policy implications of our results and concludes.

2. Model and hypotheses

The development of our hypotheses is motivated by formally illustrating the impact of a carbon price floor on the investment level under uncertain carbon price expectations. To facilitate the intuition of the empirical analysis, our simple and stylized model highlights the key mechanisms of how a change in expected carbon prices due to a price floor (trajectory) would affect individual low-carbon (hereafter: green) or fossil investment decisions and consequently the investment portfolio. Further, we assume that single investments are financed on a stand-alone basis[2] and thus ignore potential portfolio risks, which

[1] The low price floor trajectory rises from EUR 20 in 2020 to EUR 40 in 2030, which is in line with average price expectations in the survey sample. The high price floor trajectory is twice as high, rising from EUR 40 in 2020 to EUR 80 in 2030.

[2] The majority of RE projects in Germany between 2010–2015 are project financed, while the share of corporate finance increases for larger project sizes (Steffen, 2018).

would consider the covariance between different assets. The model does not consider credit constraints or other factors that potentially affect investment decisions.

Investment decisions under uncertainty have been extensively investigated from multiple viewpoints. The classical net present value approach calculates the profitability of investments by taking the difference between the present value of revenues and costs over time. The real-options-approach explicitly considers that investments are at least partially irreversible, that future payoffs are uncertain and optimizes the timing of investment (Dixit and Pindyck, 1994). Investment is delayed if the value of waiting to obtain new information exceeds the loss of early profits. The real options framework has, for example, been applied to carbon price uncertainty (Fuss et al., 2008), and investment in electricity generating technologies (Brauneis et al., 2013). Another related contribution addresses the link between carbon pricing uncertainty and fuel switching in the EU ETS (Bertrand, 2014).

Though the preceding approaches generate valuable insights from a theoretical perspective, the practical decision-making processes of individual investors might follow other patterns. For example, there are various tools for firm-level investment decisions under (deep climate) uncertainty including, cost–benefit analysis under uncertainty and with real options, robust decision making, and climate informed decision analysis (Hallegatte et al., 2012). Optimal investment for renewable energies has been shown to be ambiguous and depend on interactions between technical, economic, environmental and social factors (Strantzali and Aravossis, 2016). Ex-post analyses that consider insights from the behavioral finance literature and are rooted in work by Tversky and Kahneman (1974) econometrically show that the impact of *a priori* beliefs, policy instrument preferences or the attitude to technological risk are key drivers for RE investment (Masini and Menichetti, 2012).

2.1. A stylized model for investment decisions with a price floor

We first assume that each of j companies evaluates a set of n company-specific[3] and exogenous investment opportunities. Broadly following the classical net present value theory, but emphasizing behavioral influences and potentially irrational decision-making heuristics, we introduce a subjective expected net present value $E(V_{j,n})$. $E(V_{j,n})$ is described by $h_{j,n}$, an unknown function, that decision-makers formally or subjectively estimate for each investment opportunity. In the energy and industry sector, $h_{j,n}$ depends on the company-specific expected carbon price level $E(p_j)$ and a generic measure for price risks $R(p_j)$.

$$E(V_{j,n}) = h_{j,n}(E(p_j), R(p_j)) \tag{1}$$

Each investment opportunity is either implemented or not: If $E(V_{j,n})$ crosses a company specific threshold ρ_j, then the implementation likelihood $P(E(V_{j,n}))$ becomes 1 and the investment opportunity a planned investment, otherwise it gets rejected.

$$P(E(V_{j,n})) = \begin{cases} 1, & \text{if } E(V_{j,n}) > \rho_j. \\ 0, & \text{if } E(V_{j,n}) \leq \rho_j. \end{cases} \tag{2}$$

We define the monetary value of a planned investment as $I_{j,n}$ and $m_{j,n}$ of an investment opportunity.

$$I_{j,n} = P(E(V_{j,n})) * m_{j,n} \tag{3}$$

[3] We argue that investment opportunities are constituted of and constrained by path dependencies: For example, a wind power plant producer has obviously systematically different investment opportunities than a coal power plant construction company. But even two wind power plant producers have different histories, decision making processes and technological knowledge.

We also distinguish green from fossil investments. Generally, changes in $E(p_j)$ may increase or decrease $h_{j,n}$.[4] Higher expected carbon prices would, for example, benefit wind power investment, which would become more competitive, while the expected returns of a coal power plant would decline. We define green investments $I^{green}_{j,n}$ as investments with an increasing $h_{j,n}$ for higher $E(p_j)$ and fossil investments $I^{fossil}_{j,n}$ as the opposite.

$$I^{green}_{j,n} \quad \text{if} \quad \frac{\partial h_{j,n}}{\partial E(p_j)} > 0 \tag{4}$$

$$I^{fossil}_{j,n} \quad \text{if} \quad \frac{\partial h_{j,n}}{\partial E(p_j)} < 0 \tag{5}$$

A larger $R(p_j)$ reduces $h_{j,n}$ for both investment types as it reflects a higher price uncertainty that generally impedes investment for risk averse agents (Pratt, 1964).

$$\frac{\partial h_{j,n}}{\partial R(p_j)} < 0 \tag{6}$$

The total investment level of a company's investment portfolio I^{total}_j, is the sum of all planned green and fossil investments.

$$I^{total}_j = \sum_{n=1}^{N} I^{green}_{j,n}(E(p_j), R(p_j)) + \sum_{n=1}^{N} I^{fossil}_{j,n}(E(p_j), R(p_j)) \tag{7}$$

If the regulator introduces an unexpected carbon price floor to the cap-and-trade system, $E(p_j)$ becomes $E(p^{floor}_j)$, which equals the price path of $E(p_j)$ but is restricted by the respective price floor level or trajectory. In other words, we assume that the price floor does not affect price expectations above the floor, i.e. that the price path remains unchanged besides being constrained at the bottom. The decreased range of potential price fluctuations decreases the price risk $R(p_j)$ to $R(p^{floor}_j)$. Strictly increasing (decreasing) carbon price expectations (price risk) would require the additional assumption of a price floor trajectory above expectations.

$$E(p^{floor}_j) \geq E(p_j) \tag{8}$$

$$R(p^{floor}_j) \leq R(p_j) \tag{9}$$

A price floor may thus only reduce downward price risk, or – in addition – increase average expected carbon prices, depending on its level. Both changes to $E(p^{floor}_j)$ and $R(p^{floor}_j)$ may change the investment level with a price floor $I^{total,floor}_j$, relative to I^{total}_j.[5]

$$I^{total}_j \lesseqgtr I^{total,floor}_j = \underbrace{\sum_{n=1}^{N} I^{green}_{j,n}(\underbrace{E(p^{floor}_j)}_{+}, \underbrace{R(p^{floor}_j)}_{+})}_{+} + \underbrace{\sum_{n=1}^{N} I^{fossil}_{j,n}(\underbrace{E(p^{floor}_j)}_{-}, \underbrace{R(p^{floor}_j)}_{+})}_{+-} \tag{10}$$

2.2. Hypotheses

We develop our hypotheses based on the previous formal illustration. Specifically, we hypothesize that the investment level change depends on (i) the previous carbon price uncertainty, and (ii) the existing investment portfolio. A higher carbon price floor that requires a larger adjustment of expectations may influence investment decisions

[4] In fact, whether $h_{j,n}$ increases or decreases with $E(p_j)$ might depend on the level of $E(p_j)$. For example, investment in gas power plants might benefit from an $E(p_j)$ high enough to phase-out coal while gas would be substituted by a combination of renewables and storage after a certain threshold.

[5] In addition, the Online Appendix A.1 illustrates how the investment level would change with a price ceiling (I^{floor_up}) and with a price collar (I^{collar}) combining both price floor and ceiling. A price ceiling tends to incentivize additional fossil investment while a collar has an ambiguous impact.

more strongly. Eq. (10) illustrates, that the reduction in price uncertainty, i.e. $R(p_j^{floor})$, increases the likelihood of a higher investment level under a price floor for both investment types. This leads to our first hypothesis (HP):

HP 1. When introducing a price floor, companies otherwise facing high carbon price uncertainty increase their investment.

A price floor, however, only decreases the downward price uncertainty, leaving the upward price uncertainty intact, i.e. the risk of potential price spikes remains unchanged. Higher investment, with a price floor, should thus only be explained by a reduced downward price uncertainty, while the unchanged upward price uncertainty should not influence investment.

HP 1a. When introducing a price floor, companies otherwise facing high downward carbon price uncertainty increase their investment.

HP 1b. When introducing a price floor, companies otherwise facing high upward carbon price uncertainty do not alter their investment.

The investment level changing with a price floor is further influenced by the potentially increased carbon price expectations $E(p_j^{floor})$. The next paragraphs describe the different impacts of $E(p_j^{floor})$ on planned investment for distinct company groups, which we assume to differ in their technology portfolios, i.e. the relative magnitudes of the left and the right side of Eq. (10).

HP 2. When introducing a price floor, companies alter their investment depending on the proportion of planned fossil and green investment.

The sum of green investments (left side of Eq. (10)) can only increase under a price floor, as both the reduced uncertainty as well as the higher expected carbon price increase the likelihood of investment opportunities being planned. The investment level of companies exclusively investing to green technology should thus increase:

HP 2a. When introducing a price floor, companies with an exclusively green portfolio unambiguously increase (keep constant) their investment.

Conversely, companies with mixed portfolios comprising of green and fossil elements or exclusively fossil portfolios might increase or decrease their investment level: Fossil investment (right side of Eq. (10)) only increases under a price floor if the reduced uncertainty overcompensates for the possibly increased carbon price trajectory. Their investment level hence depends on the difference between (increased) green investment and (increased or decreased) fossil investment. This difference is ultimately constrained by the set of available, company specific investment opportunities.

HP 2b. When introducing a price floor, companies with a mixed or fossil portfolio increase or decrease their investment.

Except for green electricity companies, we are unable to derive unambiguous hypotheses about a potential increase or decrease of the investment level. The impact of a price floor on the investment level of these company groups is *a priori* unknown and subject to empirical research.

3. Methodology and data

We surveyed 113 high-level managers of German electricity and energy intensive companies between late 2018 and early 2019 to empirically investigate the effect of a carbon price floor on investment decisions. This section describes the survey approach, the sample, selected survey responses, and the empirical approach.

3.1. Survey approach

We primarily identified eligible companies via the European Union Transaction Log (EUTL) and memberships of industrial associations. The EUTL includes all EU ETS compliance companies and thus covers the largest direct CO_2 emitters, namely electricity generators and companies from energy intensive industries. We reduced the dataset to German companies and removed duplicates as well as irrelevant companies. Publicly available lists of member companies in German industrial associations provided renewable electricity producers, companies in other value chain positions of the electricity sector (e.g. fuel suppliers, manufacturers, transmission companies, distribution companies, etc.) and industrial companies outside the EU ETS. This selection of companies is assumed to consider expected carbon prices when deciding about investment decisions. Discussions with experts from industrial associations confirmed that our selection of contacted companies covered the majority of relevant actors. We supplemented our sample with data from renewable power generation technology manufacturers compiled by Rogge and Schleich (2018) and selected additional relevant companies.

The 33 survey questions (Q) cover: (i) the perception and expectations of climate policy, (ii) EUA price expectations, (iii) information on current investment, (iv) the impact of two EUA price floor scenarios on investment and (v) general information about the company. We pre-tested and reviewed the questionnaire at various stages of its development, which, in summary, included feedback and suggestions from 15 researchers and employees from industrial associations.[6] Appendix A.6 shows a translated version including aggregated responses (Q1–33), while the original questionnaire in German is available upon request.

The survey was conducted between 20.11.2018 and 25.01.2019 using different contact strategies. We obtained either personalized or general company mail addresses of high-level managers from company websites. Where possible, we selected the CFO, a specialist in energy markets or emission trading, and otherwise the CEO. Each company received at least one initial questionnaire and one reminder. Additionally, we contacted renewable power generation technology manufacturers through unpersonalized company addresses. Finally, one energy industry association (VKU) distributed our survey via their newsletter. This broad contact strategy potentially exceeds the population of interest. However, we thereby ensure that every company relevant for our survey had the possibility to participate. In total, we received 203 responses to at least one survey question. Unit-dropouts mostly occurred during the first questions and particularly when asking for numerical carbon pricing expectations (question 7 of 33).[7] Removing unit-dropouts, duplicate responses, unreasonable responses, companies with investments that are presumably neither directly nor indirectly affected by EUA prices and those which did not provide responses to both dependent variables, leads to the final sample of 113 companies.[8] The response rates differ by contact approach and data source (see Appendix A.3).

[6] The 15 contributors comprise the four authors of this paper, two employees from industry associations and nine other researchers.

[7] We tested whether early unit-dropouts show generally different response patterns to the remaining respondents, but found no robust evidence for this. Specifically, we analyzed the bivariate correlation between early unit-dropouts and the first survey questions by regressing the first responses on a dummy for early unit-dropouts. We found no significantly different first responses except for the ambition of climate policy in 2030 at the G20 level. Early dropouts expect a more ambitious global climate policy in 2030, of between 0.03 and 1.07 points on our 7-point Likert scale at the 95 percent confidence interval. However, given partially correlated answers between the first questions, and the fact that we tested 14 variables in total, we conclude that there is no strong systematic pattern of early dropouts.

[8] When removing duplicates from the same company, we kept the more comprehensive response or alternatively, the reply of the respondent with the greatest expertise. Companies that are presumably unaffected comprise two

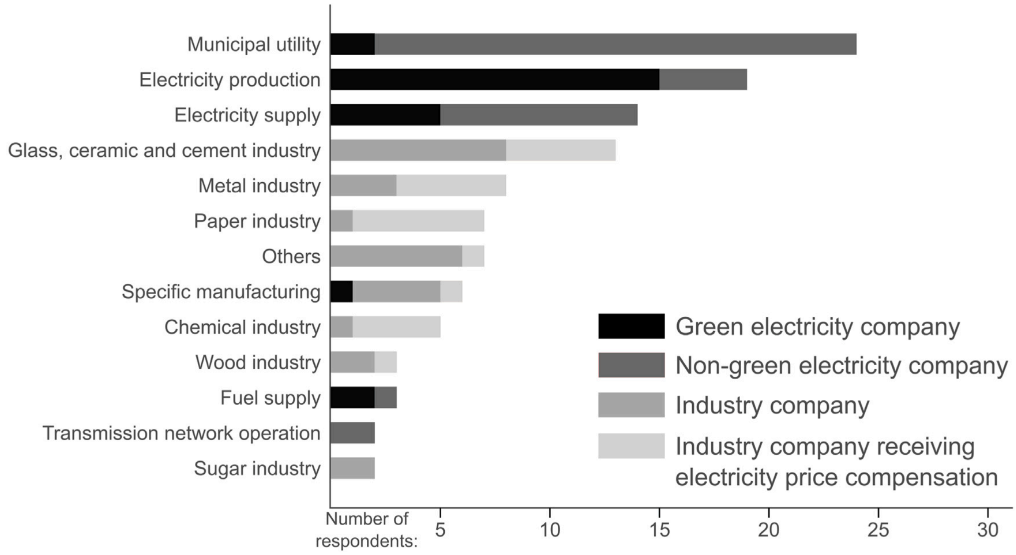


Fig. 1. Respondents by sector (N = 113). The figure shows the survey respondents grouped by sectors. If available, we use NACE rev. 2 classifications. Where this is not possible, we use additional background research. Thus we indicate the main business field, though the larger companies, in particular, may be involved in multiple sectors.

3.2. Sample description

The final sample represents the heterogeneous mix of initially contacted companies and comprises mostly large and market-leading companies, covering one-third of German carbon emissions. Fig. 1 shows the respondents by primary business sector and aggregated into four groups as used in the analysis: green electricity companies, non-green electricity companies, industry companies and industry companies receiving an electricity price compensation.[9] We classify companies based on their survey responses and additional background research.

Electricity sector companies include "Municipal utilities" (24)[10] providing electricity, heat, water and gas as well as the related grid networks. "Electricity production" companies (19) are small scale operators of single or a few power plants and associated service companies (mostly for renewable energy projects). The "Electricity supply" (14) companies comprise conventional electricity suppliers, regional electricity suppliers as well as market leading explicit renewable suppliers. We classify companies as being in the "Electricity production" sector that are exclusively involved in electricity generation, while "Electricity suppliers" comprise companies that sell electricity, whether or not they as well distribute or generate it. The sample further includes fossil and renewable "Fuel suppliers" (3) and German "Transmission network operators" (2).

Several industrial companies from various sectors are included, namely glass, ceramic and cement (13), metal (8), paper (7), chemicals (5), wood (3) and sugar (2). The sample contains market leading companies at the global (e.g. salt, sugar, cement) European (e.g. heavy plates, paper) and German (e.g. cement, oil refinery) level. Companies listed under "Others" (7), for example, include companies from the textile or the automotive industry and manufacturers of multiple products. The "specific manufacturing" (6) companies include welding, lasers, and pumps etc.

The sector classifications mostly rely on survey responses while using additional background research where data are missing for green and EU ETS companies. Our response sample includes 61 companies (57 percent) that are EU ETS compliant. These companies correspond to roughly 33 percent of verified German CO_2 emissions of the EU ETS in 2017.[11] We emphasize that the sample is not sufficiently large to statistically represent all German companies with investments affected by carbon prices. However, the sample mostly comprises large companies with two thirds having annual turnovers above EUR 50 m and half of them having more than 250 employees of several market leading companies in their respective economic sectors. The business focus of the majority of companies is on the German (79 percent) or German and European markets (93 percent).

3.3. Descriptive analysis

We provide descriptive outcomes of selected survey sections and outcomes to give a better insight into our sample.

Perceptions and expectations of climate policy

We elicit the perception of different climate policy aspects today and expectations for 2030 and 2050 for Germany, the European Union and the G20 as well as drivers of the German climate policy ambition

consultancies, one company group without own investments, one logistics company, one IT-provider, and one energy trader. Finally, we ignored responses with apparently unreasonable EUA price expectations, namely one observation with EUR 0 for each year and two with extremely high EUA price estimates for 2030 and corresponding confidence intervals. These outlier expectations otherwise strongly influence the results.

[9] The electricity price compensation has been introduced to prevent the relocation of production activities outside the European Union by granting state aid for indirect CO_2-costs that arise from higher electricity prices of emissions trading. In 2018, 898 installations of 326 undertakings were granted EUR 219 m, with 40 percent from the chemical industry, 24 percent from the iron and steel industry, 19 percent from the paper industry while the non-ferrous metal industry accounted for 17 percent. Of the 898 installations, 481 participated in the EU ETS. Their share of the total electricity price compensation is 69 percent (German Environment Agency, 2020) Though EU ETS participation is no pre-requirement for reimbursements, due to our search strategy (see Section 3.1) our sample contains only one company that receives an electricity price compensation without participating in the EU ETS.

[10] Number of included companies.

[11] We use the "Verified Emissions for 2017" version from the 01.04.2018 for the calculation. Responses from holdings or parent companies were applied to all subsidiaries of the company group. If data for 2017 was not available, we used the largely similar data for 2016.

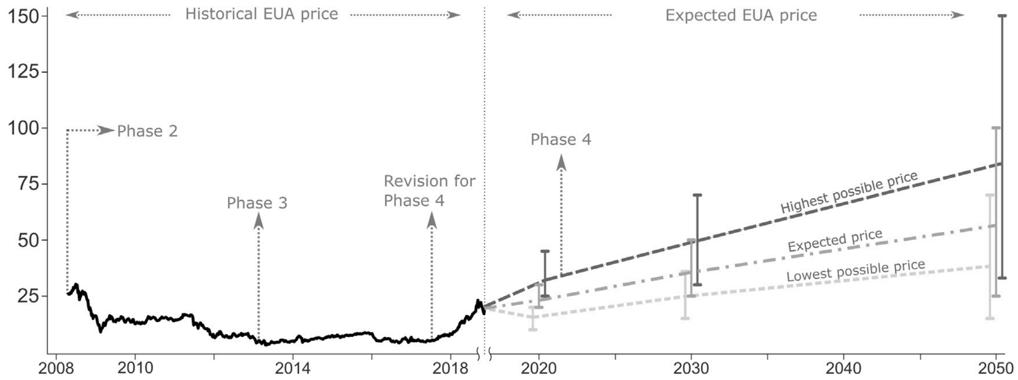


Fig. 2. EUA price development. The figure shows historical and expected EUA prices. Historical prices are included from 2008 until the time of our survey in November 2018 (Quandl: ECX EUA futures, continuous contract). In our survey we elicit the expected mean EUA price as well as the highest and lowest possible mean price that will most likely not be exceeded or undercut, for 2020, 2030 and 2050. The vertical bars show the 10th and 90th percentile responses.

for 2030 (Q1–6). Overall, the responses reveal higher expected climate policy ambitions for the future than today, but a rather low belief in meeting 2030 climate targets or a decarbonized economy in 2050, even though a carbon price floor for the EU or Germany seem rather likely. The mean perceived and expected climate policy stringency decreases with a higher governance level, though responses for Europe and Germany are equivalent and those for the G20 far lower. The "Public opinion" (48 percent), "Energy prices" (43 percent) and "Costs of a renewable energy system" (42 percent) are the most important drivers of German climate policy ambitions in 2030. Even though respondents perceive the implementation of a German or EU price floor by 2030 as "rather likely" on average, the survey questions neither specify a price floor level, nor other reform details.

EUA price expectations

We assess EUA price expectations and what drives those expectations (Q6–8). Fig. 2 shows the survey responses and the historic EUA price development up until the time of the survey.

Specifically, we elicit the expected average levels of EUA prices (hereafter "expected EUA price") and the highest and (lowest) possible average price level (hereafter "possible EUA price") that will most likely not be exceeded (undercut), for the years 2020, 2030 and 2050. The mean expected EUA price considerably increases over time, from EUR 23 in 2020 through EUR 36 in 2030 to EUR 57 in 2050. Despite this, the respondents deviate substantially in their prognoses: for example, the lowest possible EUA price of the 90th percentile for 2030 (EUR 36) is higher than the highest possible EUA price of the 10th percentile (EUR 30). In other words, the lowest possible EUA price for some respondents is considerably greater than the highest possible EUA price for others.

Previous surveys, mostly focusing on the year 2020, reported lower expected EUA prices than anticipated by our respondents. They gave estimates of: (i) EUR 11 in 2016 and 2017 and almost EUR 19 in 2018 (Nordeng and Kolos, 2016, 2017; Melum, 2018), (ii) EUR 13 in spring 2016 (Osberghaus et al., 2016) and, (iii) considerably higher at EUR 40 in 2009[12] (Martin et al., 2012). The expected prices suggest a correlation with price levels during the respective survey periods.[13] Similarly, other price forecast scenarios computed by various analysts show an upward moving pattern from 2018 to 2019. They also reflect our diverging survey responses as price expectations for 2024 range between almost EUR 15 and 45 (Marcu et al., 2019). It is noteworthy that the price level in early 2022 of more than EUR 90 significantly exceeds expected prices for 2020 or even 2030, which further underlines the price uncertainty faced by investors.

To investigate why EUA price expectations differ, we directly elicit the impact of eleven potential drivers: The most influential drivers are *additional potential ETS reforms*, *national climate policies of EU member states* and *economic cycles*, while all factors appear to be generally relevant. The responses emphasize the influence of political reforms on EUA price expectations, which aligns with previous *ex post* analyses that show a high EUA price responsiveness to political events (Koch et al., 2016).

Investment patterns

We elicit details about the status quo investment in Germany, such as level, timing, portfolio, planning horizon and factors influencing investment decisions (Q9–19).[14]

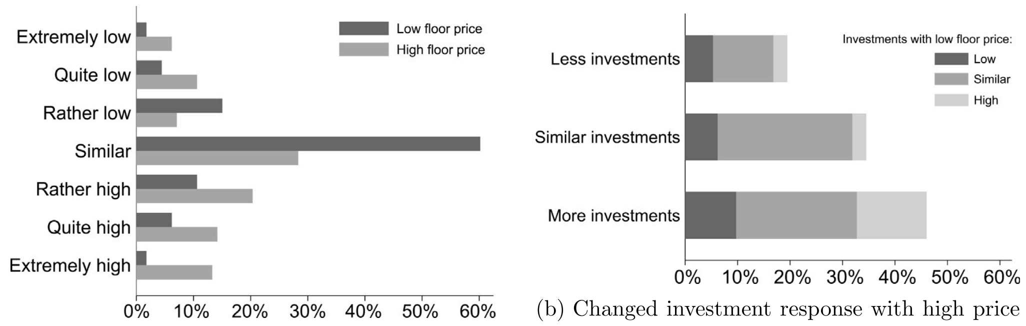
The mean investment level is rather high compared to the three years before the survey, while the mean timing of investments is similar. There is a correlation between high and earlier than planned investment, which suggests that in late 2018 some companies seem to experience a boom, while others decrease and delay their plans. When asked to tick components of the current investment portfolio, a majority selected *more efficient production technologies* and *new business fields and products* as well as *reinvestment in the current business model*. Only a few selected to invest in *research and development*. The influence on current investment decisions is medium to rather high for *price expectations* for *electricity*, *EUAs* and *energy*, while political factors, such as the *credibility of EU ETS and EU climate policy in total* or *national climate policies*, are least influential. Two thirds have planning horizons of less than 10 years.

EUA price floor scenarios

[12] The annual carbon market survey by Thomson Reuters elicits EUA price expectations of companies across multiple countries, sectors and carbon markets for the year 2020. From 2009 to 2016 the KfW/ZWE published the CO_2 Barometer, a survey among German EU ETS compliance companies. The latest CO_2 Barometer from 2016 in addition reports almost EUR 25 for the year 2030. The analysis of Martin et al. (2012) is based on 800 structured phone interviews with managers from manufacturing facilities in six countries across 16 industrial sectors. The results indicate substantial sectoral differences, ranging from average estimates of e.g. EUR 23.50 in the fuels sector to EUR 48.10 in the glass sector with a total average estimate of EUR 40.

[13] For example, the higher expectations from 2018 of the Thomson Reuters survey correspond to an EUA price of EUR 13 at the time of the survey. The phone interviews of Martin et al. (2012) were conducted between August and October in the year 2009 during which the EUA price fluctuated around EUR 25.

[14] Specifically, the survey elicits the investment portfolio by type, energy carrier and business field. Furthermore, this section asks whether companies receive an electricity price compensation, participate in EUA trading and whether explicit EUA price prognoses are considered for planned investment.



(a) Investment levels compared to status quo

(b) Changed investment response with high price floor compared to low price floor

Fig. 3. Investment level for scenarios compared to status quo Panel (a) shows the change of the investment level compared to the status quo using a 7-point Likert scale that ranges from "Extremely low" to an "Extremely high" for both the low price floor and the high price floor scenario. The figure shows the response to the question: "How high or low is the investment level of your company compared to your current plans with scenario 1(2)". Panel (b) shows how the responses changed from the low price floor to the high price floor scenario. The stacked columns indicate the investment response to the low price floor scenario.

We ask how a low price floor and a high price floor would change level, timing and portfolio of investment compared to the status quo (Q20–26). The low price floor scenario starts with an EUA price of EUR 20 in 2020, linearly increasing to EUR 40 in 2030. This is broadly in line with expected EUA prices for 2020 although, by 2030, the scenario price rises slightly above mean expectations.[15] For many respondents this price trajectory thus has the effect of adding insurance against downward price risk. The high price floor scenario starts with EUR 40 in 2020 and increases to EUR 80 in 2030. In addition to introducing the institution of a price floor, this adds the effect of increasing the expected carbon price trajectory for almost all respondents. The high price floor trajectory broadly corresponds to the upper carbon price range suggested by the Stern–Stiglitz report, while the low price floor is slightly below this suggested price range (High-Level Commission on Carbon Prices, 2017).

Fig. 3(a) shows changes of the investment level for both scenarios. A low price floor trajectory leaves the investment level unchanged for the majority of companies, though some increase or decrease their investment. By contrast, with a high price floor trajectory almost half of the respondents report increased investment volumes, while only 28 (24) percent indicate unchanged (decreased) investment. This demonstrates the relevance of carbon pricing for company investment decisions, and the importance of the price floor level and trajectory for investment. Furthermore, we show the changes between investment responses to the low and the high price floor trajectory (see Fig. 3(b)). Here, 46 percent increase, 35 percent maintain and 19 percent decrease their investment level with the high price floor scenario. Interestingly, 26 percent do not change their investment level at all, while ten percent decrease investment under a low price floor, but increase it under a high price floor.

Investment timing and portfolio would similarly remain largely unchanged under a low price floor, while a high price floor would lead to earlier investment into a more diversified portfolio. Comparing both scenario responses in detail, shows that the investment timing would remain unchanged for 69 percent under a low price floor and for 36 percent under a high price floor. The proportion of respondents investing earlier would increase from 22 percent to 51 percent, while the portfolio would remain unchanged for 42 and 20 percent, respectively. However, others would extend their portfolio with additional technologies/measures (39 and 47 percent), new business fields (23 and 36 percent) or additional energy carriers (13 and 25 percent). The proportion of respondents decreasing their portfolio would grow from 5 to 19 percent.

[15] In 2020, only 8 percent expect less than EUR 20 while almost 70 percent expect less than EUR 40 in 2030.

3.4. Empirical approach

We use our data to empirically test how a price floor affects the investment level of a company. With respect to our formal illustration, we define this investment level change ΔI_j as

$$\Delta I_j = I_j^{total,floor} - I_j^{total} \tag{11}$$

i.e. the difference between the level of all investment opportunities that are profitable with a price floor and the level of previously planned investment. The survey directly elicits ΔI_j, i.e. how the investment level would change relative to the status quo, first, with a low price floor trajectory and second, with a high price floor trajectory (see Section 3.3 for more details). Two dependent variables indicate whether the investment level would be lower, similar, or higher for the respective price trajectory

$$y = \begin{cases} 0, & \text{if } \Delta I_j < 0. \\ 1, & \text{if } \Delta I_j = 0. \\ 2, & \text{if } \Delta I_j > 0. \end{cases} \tag{12}$$

In addition, we analyze why the investment response of companies alters between the scenarios. Consistent with Eq. (14), a third dependent variable indicates whether the investment response with a high price floor is lower, similar or higher, than the response to a low price floor.[16]

We use an ordered probit model in line with our ordered dependent variables. The continuous latent variable y^* is correlated with the three observable investment level changes (lower ($y = 0$), equivalent ($y = 1$) and higher ($y = 2$)) and measures the unobserved impact of the independent variables. We assume a linear relationship between the independent variables $\mathbf{X}$ and y^*. Without company-specific indices, we obtain

$$y^* = \mathbf{X}\beta + \epsilon \tag{13}$$

Here, y^* may vary between $-\infty$ and ∞, while ϵ is a normally distributed error term. The investment level change y relates to y^* by

$$y = \begin{cases} 0, & \text{if } y^* < 0. \\ 1, & \text{if } 0 < y^* < \mu_1. \\ 2, & \text{if } \mu_1 < y^*. \end{cases} \tag{14}$$

[16] The survey elicits the investment level with the price floor relative to the status quo using a 7-point Likert Scale between "Extremely low" = 1 and "Extremely high" = 7. This third dependent variable indicates whether the numerical difference between the high and the low price floor trajectory response is negative (= 0), zero (= 1), or positive (= 2).

Table 1
Variable summary statistics.

Dependent variables	Outcome	Frequency	Percentage share		
Low price floor	Decrease	24	21.24		
	Similar	68	60.18		
	Increase	21	18.58		
High price floor	Decrease	27	23.89		
	Similar	32	28.32		
	Increase	54	47.79		
Low to high	Decrease	22	19.47		
	Similar	39	34.51		
	Increase	52	46.02		
Independent variables	**Frequency**	**Mean**	**Standard deviation**	**Minimum**	**Maximum**
Downward uncertainty	109	0.30	0.16	0.00	0.88
Upward uncertainty	109	0.39	0.28	0.00	1.86
Green electricity company	113	0.22	0.42	0.00	1.00
Non-green electricity company	113	0.34	0.47	0.00	1.00
Industry company	113	0.24	0.43	0.00	1.00
Industry company receiving electricity price compensation	113	0.20	0.40	0.00	1.00

Note. The upper part shows the frequency and the percentage share of the three possible outcomes of the dependent variables. The lower part shows frequency, mean, standard deviation, minimum value and maximum value of all independent variables.

with μ_1 as an unknown threshold parameter.

The following equation provides the probabilities of estimating lower ($y = 0$), equivalent ($y = 1$) or higher ($y = 2$) investment levels, with Φ denoting the standard normal cumulative distribution function.

$$\begin{aligned} P(y=0|X) &= \Phi(-X\beta) \\ P(y=1|X) &= \Phi(\mu_1 - X\beta) - \Phi(-X\beta) \\ P(y=2|X) &= 1 - \Phi(\mu_1 - X\beta) \end{aligned} \quad (15)$$

The parameters are estimated by the maximum likelihood method. The magnitude of the probability change for each outcome induced by the independent variables is shown via the marginal effects at means.

For robustness we test three alternative dependent variable specifications: We use OLS estimation to regress the discrete and normalized Likert scale responses. Furthermore, we use a Probit version with increased investment ($=1$) and decreased investment or similar investment ($=0$). Analogously, for the change in the investment level from the low price floor to the high price floor, we use an OLS regression framework with the initial change in Likert scale steps, i.e. the high price floor minus the low price floor response. Another regression uses normalized values. Finally, we also create a binary version of the dependent variable having only two outcomes, an increasing investment level ($=1$) and a similar or decreasing level ($=0$).

3.5. Variables

This section describes our main dependent and independent variables, Table 1 shows the summary statistics.

In line with our regression model (see Section 3.4), we receive data for ΔI_j by aggregating the Likert scale responses for both scenarios indicating a decreased ($=0$), similar ($=1$) or increased ($=2$) investment. A third ordinal dependent variable captures whether the investment response between the low price floor and the high price floor scenario decreases ($=0$), is similar ($=1$) or increases ($=2$).

HP 1(a–b) addresses the impact of EUA price uncertainty (downward and upward) on the investment response to a floor price. We derive our uncertainty measures by using survey information on the expected EUA price $E(p_j)$ and the highest ($E(p_j^{max})$) and lowest $E(p_j^{min})$ possible EUA price. We specify the generic price risk $R(p_j)$ from our model as *Downward uncertainty* $U(p_j)^{down}$ and *Upward uncertainty* $U(p_j)^{up}$ as the normalized downwards and upwards deviation from the expected price (cf. Nemet et al., 2017a):

$$U(p_j)^{down} = \frac{E(p_j) - E(p_j^{min})}{E(p_j)} \quad (16)$$

$$U(p_j)^{up} = \frac{E(p_j^{max}) - E(p_j)}{E(p_j)} \quad (17)$$

To test HP 2(a–b), we aggregate the previously described primary business sectors to our four company types (see Fig. 1). The majority of *Green electricity companies* are located in the Electricity production (60 percent) and the Electricity supply (20 percent) sectors, while the remainder comprises green municipal utilities, fuel suppliers and one specific manufacturer. *Non-green electricity companies* are mostly “Municipal utilities” (58 percent), electricity suppliers (24 percent) and electricity producers (11 percent). Three remaining companies are two transmission network operators and one fuel supplier. *Industry companies* and *Industry companies receiving electricity price compensation* cover companies from different industries, namely glass, ceramic and cement (30 and 22 percent), metal (11 and 22 percent), paper (4 and 26 percent), chemical (4 and 17 percent), wood (7 and 4 percent) and sugar (7 and 0 percent), with other industries (22 and 4 percent) and specific manufacturing companies (15 and 4 percent). We assume that *Green electricity companies* have exclusively green investment portfolios, which makes them eligible for testing HP 2a. The remaining three company groups may have either mixed or fossil portfolios, which allows us to test HP 2b.

4. Results

We find that EU ETS companies currently receiving an electricity price compensation are already likely to decrease their investment under a low price floor, whereas green electricity companies systematically report higher and a more diversified investment only under a high floor. Companies with a higher downward price uncertainty increase their investment level only in response to a high, compared to a low price floor trajectory. Portfolio changes vary strongly between the company groups and, consistent with the investment level, are more pronounced under a high price floor.

To test our hypotheses, we regress the investment level change on carbon price uncertainty (HP 1a–b) and company types (HP 2a–b). Tables 2–4 show the ordered probit coefficients, marginal effects at the mean and the predicted probabilities. For the company group variable, the predicted probabilities indicate the likelihood of decreasing, maintaining or increasing investment. We furthermore report the marginal effects at the mean including their standard deviation, which indicate the magnitude and significance of the difference between the base group of non-green electricity companies and the others. For the continuous uncertainty variables, the marginal effects indicate the difference in likelihood of decreasing, maintaining or increasing investment, depending on the magnitude of uncertainty. Robustness

Table 2
Low price floor results.

		Marginal effects			Predicted probabilities		
	Coefficient	Decrease	Similar	Increase	Decrease	Similar	Increase
Downward uncertainty	0.475	−0.125	0.009	0.116			
	(0.670)	(0.180)	(0.030)	(0.163)			
Upward uncertainty	−0.258	0.068	−0.005	−0.063			
	(0.521)	(0.137)	(0.016)	(0.128)			
Green electricity company	0.523	−0.101**	−0.062	0.163	0.070	0.596***	0.333***
	(0.325)	(0.051)	(0.070)	(0.112)	(0.046)	(0.074)	(0.108)
Non-green electricity company	0.000	0.000	0.000	0.000	0.171***	0.659***	0.170***
	(.)	(.)	(.)	(.)	(0.042)	(0.048)	(0.040)
Industry company	0.066	−0.016	−0.001	0.017	0.155**	0.658***	0.187**
	(0.314)	(0.076)	(0.009)	(0.084)	(0.071)	(0.049)	(0.080)
Industry company receiving electricity price compensation	−0.833***	0.282***	−0.149**	−0.133***	0.454***	0.509***	0.037*
	(0.259)	(0.093)	(0.070)	(0.040)	(0.090)	(0.078)	(0.020)
Cut 1	−0.909***						
	(0.295)						
Cut 2	0.994***						
	(0.280)						
N	109						
Pseudo R^2	0.074						

Note. The table shows the ordered probit regression coefficients, the marginal effects and the predicted probabilities (both at means) for decreased (= 0), similar (= 1) or increased (= 2) investment under a low price floor. Robust standard errors are in parentheses.
* p < .1.
** p < .05.
*** p < .01.

checks with alternative dependent variables and model specifications with additional explanatory variables are shown in Appendix A.5.

The next subsections discuss investment responses in detail. We analyze how the investment level (see 4.1) changes with a low floor price and a price floor higher than the status quo. We also compare how both responses differ. In addition, we discuss how the investment portfolio would change for each company group (see 4.2). We finally discuss the limitations of our approach (see 4.3).

4.1. Investment level

Low price floor

Under a low price floor (see Table 2), downward or upward uncertainty in expected carbon prices does not affect investment level changes. In a similar vein, each company group is most likely to maintain their investment level (more than 50 percent). Green electricity companies are a notable exception, as the predicted probabilities suggest a higher likelihood of them increasing their investment level (33 percent). However, the marginal effects at the mean do not allow us to conclude a significantly different response to that of non-green electricity companies. Yet, the likelihood of decreased investment is very small (7 percent). Non-green electricity companies and industry companies overall follow the sample mean; the likelihood of them increasing or decreasing investment are small and almost equivalent (between 15 and 19 percent). Industry companies receiving an electricity price compensation are almost equally likely (45 percent) to decrease their investment level than to keep it unchanged (51 percent). Increased investment is highly unlikely (4 percent) and their responses differ significantly from the base group.

The finding for companies receiving an electricity price compensation requires further elaboration. Thus far, these companies largely receive compensation for indirect carbon emissions embedded in their electricity consumption and related increases in power prices that affect their production costs. Nevertheless, their carbon costs are above zero and stringency slightly increases under the current regulation by step-wise reducing the share of compensated electricity.[17] The future of the electricity price compensation was generally uncertain as the underlying EU guidelines were being revised for the fourth trading period that started in 2021 (German Environment Agency, 2020).[18] In addition, the electricity price compensation applies to a specific set of industrial sectors that may be more carbon intensive than others. Higher and more certain expected carbon costs, in combination with a price floor signaling a greater climate policy ambition, may contribute to decreased investment for this particularly affected group. Section 5.2 discusses further implications of decreased investment levels, such as abolished fossil investment or investment relocation.

High price floor

Under a high price floor (see Table 3), downward or upward carbon price uncertainty still have no impact on changes in the investment level. We find that green electricity companies are particularly likely to increase their investment (86 percent). Other company groups having mixed or fossil portfolios are likely to either increase or decrease their investment level. Higher investment levels are the most likely response of non-green electricity companies and industry companies (50 and 45 percent). Nevertheless, some maintain constant investment levels (32 and 34 percent) or decrease investment (18 and 21 percent). Industry companies receiving an electricity price compensation are, again, particularly likely to decrease their investment (57 percent). Also, for them a high price floor makes a higher investment level more likely than under a low price floor (14 percent compared to 4 percent), which suggests heterogeneous response patterns within this group.

Thus the goal of increasing investment of most green electricity companies seems to require a sufficiently high price floor trajectory. Without a high and certain carbon price, other policies that are explicitly directed towards green electricity companies, such as feed-in-tariffs, may be more effective.

Comparing low and high price floors

We analyze why investment responses to the low and the high price floor change, highlighting the sensitivity of investment decisions to different price floor trajectories (see Table 4). For example, some companies reduce investment under a low price floor, but increase

[17] Compensations are either based on product specific electricity consumption benchmarks, or the direct electricity consumption multiplied by a “fallback-factor”, that decreases step-wise from 0.85 to 0.75 from 2013 to 2020.

[18] The new draft regulation is framed under the European Green New deal narrative, which suggests increasing stringency. This draft has however been published after dissemination of our survey.

Table 3
High price floor results.

	Coefficient	Marginal effects Decrease	Similar	Increase	Predicted probabilities Decrease	Similar	Increase
Downward uncertainty	0.867	−0.228	−0.118	0.346			
	(0.782)	(0.210)	(0.109)	(0.312)			
Upward uncertainty	0.222	−0.059	−0.030	0.089			
	(0.411)	(0.110)	(0.054)	(0.164)			
Green electricity company	1.100***	−0.157***	−0.208***	0.366***	0.022	0.115**	0.863***
	(0.377)	(0.042)	(0.075)	(0.100)	(0.020)	(0.057)	(0.075)
Non-green electricity company	0.000	0.000	0.000	0.000	0.179***	0.324***	0.497***
	(.)	(.)	(.)	(.)	(0.041)	(0.055)	(0.068)
Industry company	−0.124	0.034	0.015	−0.049	0.213***	0.339***	0.448***
	(0.284)	(0.080)	(0.033)	(0.113)	(0.073)	(0.056)	(0.096)
Industry company receiving	−1.098***	0.392***	−0.029	−0.363***	0.571***	0.294***	0.135*
electricity price compensation	(0.372)	(0.137)	(0.063)	(0.094)	(0.127)	(0.064)	(0.079)
Cut 1	−0.576*						
	(0.331)						
Cut 2	0.350						
	(0.331)						
N	109						
Pseudo R^2	0.149						

Notes. The table shows the ordered probit regression coefficients, the marginal effects and the predicted probabilities (both at means) for decreased (= 0), similar (= 1) or increased (= 2) investment under a low price floor. Robust standard errors are in parentheses.
* p < .1.
** p < .05.
*** p < .01.

investment under a high floor. Others report the opposite. In fact, all possible combinations of responses occur (see Fig. 3(b)).

We find that companies with a higher downward price uncertainty, regardless of the company type, are more likely to report a higher investment response. There is no such effect for companies with a high upward price uncertainty. The remaining regression results largely mirror the high price floor outcomes: green electricity companies are highly likely to increase their relative investment response (82 percent), industry companies receiving an electricity price compensation are particularly likely to decrease their relative investment response (42 percent), and non-green electricity companies and industry companies are equally likely to increase their relative investment response (47 and 42 percent).

Finding significant differences in investment levels for downward price uncertainty between both scenario responses, and not for each respective scenario, implies that companies with more uncertain carbon price expectations are particularly sensitive to the level of a price floor trajectory.

4.2. Investment portfolio

The investment portfolio in the status quo and under a price floor may shed light on the question why some companies increase their investment and others not. We thus complement and explain the investment level changes by analyzing the *ex ante* investment portfolio (see Table 5) and how the portfolio would change *ex post* to the introduction of a low and high price floor for each company group (see Fig. 4).[19]

The investment portfolio of green electricity companies indicates the highest level of innovation. The most frequently selected status quo portfolio category is investment in new business fields (75 percent), which is above the sample average (50 percent). Compared to non-green electricity companies, more than twice as many invest in research and development (33 percent). Efforts to reduce energy intensity and climate relevant emissions are less prevalent than average, which reflects differences in the business models between green electricity companies and the other company groups. Under a low price floor, half would extend their portfolio, especially by entering new business fields (41 percent) and deploying new technologies (32 percent). However almost all green companies would expand their portfolio under a high price floor. An even larger share would then enter new business fields (64 percent) and adopt new technologies (59 percent), while investment in new energy carriers would also be triggered (41 percent). Overall, green electricity companies have the largest share of ticks in all three categories of additional investment. Even though some would already adjust their portfolio under a low price floor, the results show that only a high floor would lead to a significant portfolio diversification in combination with, as previously shown, higher investment levels.

Non-green electricity companies invest mainly, but not exclusively, in support of current business practices, and neither price floor triggers substantial diversification. In the status quo, a large proportion invest in the current business model (68 percent), or efficiency and new business fields (both 49 percent). Only a few expand their production capacity (22 percent), which may reflect the last two decades of the ongoing and persistently debated German energy transition (“Energiewende”). A low price floor would foster portfolio expansions of less than a third in the following areas: new technologies (27 percent), new business fields (21 percent) or deploying new energy carriers (18 percent). In comparison with green electricity companies, only the share of respondents adopting new, and presumably, renewable energy carriers is higher. Under a high price floor, many respondents continue to report an unchanged investment portfolio (34 percent). Ticks for other categories increase moderately, including complete portfolio restructurings (9 percent) and reductions (17 percent). The relatively small portfolio adjustments suggest that portfolios may already include low-carbon elements, such as renewable electricity sources, green electricity grids or other modern energy services. The investment level would increase for almost half the companies under a high price floor, which suggests that low-carbon portfolio elements would increase and overcompensate for abolished fossil investment.

Industry companies already report the largest ongoing diversification and comparatively the largest portfolio changes under a low price floor. In the status quo, they focus on efficiency (87 percent), decreasing energy intensity (63 percent) and production capacity increases (55 percent). Every other category is also ticked by at least 40 percent of respondents. Industry companies pay for direct carbon emissions from production processes and indirect carbon emissions embedded in their electricity consumption. Reducing direct carbon emissions

[19] In addition, Appendix A.2 shows how the portfolio would change under a low and a higher price floor by company group and investment level change.

Table 4
Low to high price floor results.

	Coefficient	Marginal effects Decrease	Similar	Increase	Predicted probabilities Decrease	Similar	Increase
Downward uncertainty	1.937**	−0.426**	−0.346**	0.771**			
	(0.833)	(0.188)	(0.166)	(0.331)			
Upward uncertainty	0.098	−0.022	−0.017	0.039			
	(0.387)	(0.086)	(0.068)	(0.154)			
Green electricity company	1.000***	−0.122***	−0.231***	0.354***	0.019	0.161***	0.820***
	(0.314)	(0.040)	(0.071)	(0.097)	(0.013)	(0.060)	(0.071)
Non-green electricity company	0.000	0.000	0.000	0.000	0.141***	0.392***	0.466***
	(.)	(.)	(.)	(.)	(0.039)	(0.058)	(0.072)
Industry company	−0.124	0.030	0.019	−0.049	0.171***	0.412***	0.417***
	(0.287)	(0.070)	(0.043)	(0.113)	(0.062)	(0.059)	(0.094)
Industry company receiving electricity price compensation	−0.861**	0.274**	0.020	−0.294***	0.415***	0.412***	0.172**
	(0.356)	(0.127)	(0.050)	(0.103)	(0.121)	(0.060)	(0.086)
Cut 1	−0.464						
	(0.333)						
Cut 2	0.695**						
	(0.349)						
Observations	109						
Pseudo R^2	0.135						

Note. The table shows the ordered probit regression coefficients, the marginal effects and the predicted probabilities (both at means) for decreased (= 0), similar (= 1) or increased (= 2) investment under a low price floor. Robust standard errors are in parentheses.
* p < .1.
** p < .05.
*** p < .01.

Table 5
Investment portfolio status quo.

	Green electricity company	Non-green electricity company	Industry company	Industry company receiving electricity price compensation	Sample average
New business fields/products	75.00	48.65	44.44	30.43	49.55
Research and development	33.33	13.51	48.15	13.04	26.13
Reinvesting to current business model	54.17	67.57	44.44	56.52	56.76
Expansion of production capacity	37.50	21.62	51.85	60.87	40.54
More efficient production technologies/processes	33.33	48.65	85.19	73.91	59.46
Decrease of energy intensity	12.50	18.92	62.96	43.48	33.33
Decrease of climate relevant emissions	29.17	45.95	44.44	30.43	38.74

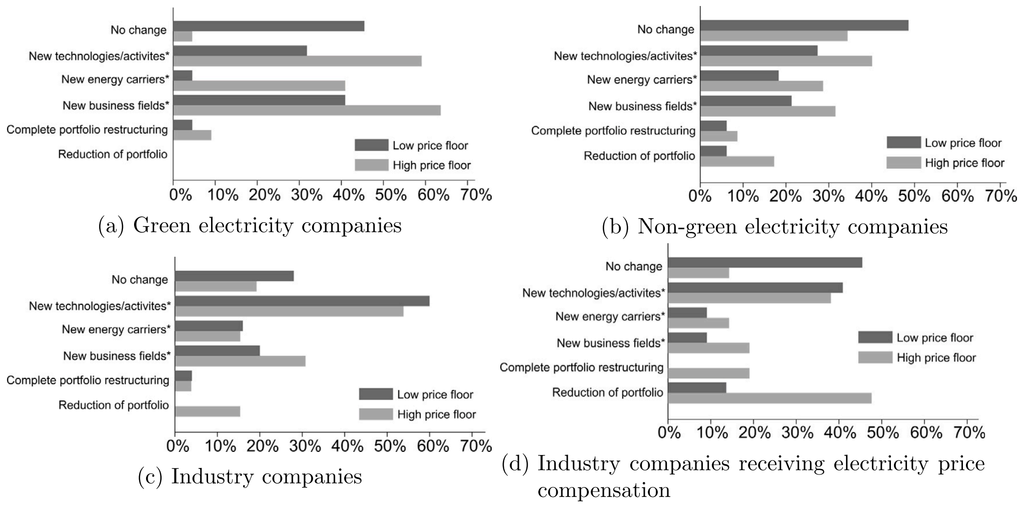
Note. The table shows the share in percentage points of status quo investment portfolio elements by company type (column 1–4) and the sample average (column 5). The lines show the different elements of the investment portfolio.

from production processes requires investment in green and innovative production processes, that may or may not be feasible, depending on the specific industrial sector. Under a low price floor, less than a third report an unchanged portfolio (28 percent), while a large proportion invest in new technologies (60 percent) and a few in new business fields (20 percent) or energy carriers (16 percent). The portfolio adjusts relatively consistently in response to a low and a high price floor, though a notable 15 percent would reduce their portfolio under a high price floor. In summary, we find ongoing diversification efforts, where low-carbon investments would mostly replace (overcompensate for) fossil investments under a low (high) price floor.

Industry companies receiving an electricity price compensation show the least innovative investment portfolio in the status quo, although especially a high price floor would induce comprehensive portfolio reductions. In the status quo, investment focuses on efficiency (75 percent), a higher production capacity (62 percent) and the current business model (56 percent). Least pronounced is innovation related investment in new business models (30 percent) and research and development (13 percent). Under a low price floor, those changing their portfolio, particularly invest in new technologies (41 percent). Only a few would invest in other fields, while some would even reduce their portfolio (14 percent). This share increases under a high price floor, with almost half reducing (48 percent) and every fifth company (19 percent) completely restructuring their portfolio. Portfolio reductions suggest abolished unprofitable fossil investment plans, while restructurings suggest diversification efforts. Considering the likelihood of almost 60 percent of those companies decreasing their investment level under a high price floor, indicates that additional low-carbon investment, for example into new technologies, would not quantitatively compensate for abolished fossil investment.

4.3. Limitations

Our analysis faces some challenges that might influence the validity of results. First, our sample size is limited. Although our sample includes market-leading German electricity and energy intensive companies covering roughly 33 percent of verified German CO2 emissions, 113 responses are not comprehensive. A larger sample would allow for a more sectorally disaggregated analysis providing more nuanced findings, given that related research focusing on innovation shows different reactions across sectors (Borghesi et al., 2015). However, our analysis provides valuable insights into investment responses of relevant company in their specific sectors.



(a) Green electricity companies

(b) Non-green electricity companies

(c) Industry companies

(d) Industry companies receiving electricity price compensation

Fig. 4. Investment portfolio change with price floor. Panel (a–d) show change in of the investment portfolio for a low price floor (dark gray) and a high price floor (light gray) compared to the status quo for the four respondent groups.
*extending the portfolio.

Second, we cannot rule out strategic responses and selection into the sample. While companies that are primarily located in the renewable energy sector have an incentive to report overly optimistic investment responses under a price floor, there is at least an equally strong incentive for carbon intensive companies to signal decreasing investment. The political implications of our study caused the representative from one large German electricity provider to refuse to participate. However, strategic responses are more likely if respondents expect to have an impact on policy-making. During the time of our survey, the public debate on carbon pricing in Germany, even though it was an ongoing topic, was minimal and only accelerated after the survey was closed in early/mid 2019.

Third, responses may be biased due to a combination of stated preferences and our hypothetical and simple survey scenarios. Creating more realistic but hence complex scenarios faces a trade-off with a higher cognitive burden, which would increase dropouts. More complex scenarios may, however, only approximate real investment decisions, as these depend on numerous subtle mechanisms, such as the perceived credibility of a specific policy reform. The absence of high carbon prices in the past prevented ex-post analyses and thus rendered analyzing stated preferences as the only option.

Finally, we cannot ensure that it were exclusively high-level managers who provided the survey responses. However, roughly half of the respondents voluntarily entered their personalized e-mail address for potential follow-up questions. This was either the contact mail initially used, or that of another high-level manager in the same company.

5. Conclusion and policy implications

Based on a survey of 113 companies in the German electricity sector and energy intensive companies we provide empirical evidence on the investment response to a high and a low carbon price floor trajectory. We show that a floor price in the EU ETS could foster low-carbon investment, while the specific price trajectory is crucial. A low price floor trajectory, providing insurance against downward price fluctuations, leaves investment unchanged for most companies in our sample. This however changes with a sufficiently high carbon price, which leads to higher low-carbon investment for the majority of companies. Responses systematically differ between company types and levels of uncertainty in carbon price expectations. In particular, green electricity companies would increase their investment level and extend their portfolios, while energy intensive companies would decrease investment, already when faced with a low price floor trajectory.

Our results show that a carbon price floor would affect companies' investment decisions differently. In this section, we discuss the underlying reasons. We examine additional survey responses[20] to discuss (i) the impact of expectations (on carbon prices and climate policy, in general) and the relevance of carbon prices for specific companies' investment decisions, (ii) implications of adjusted investment portfolios, and (iii) how the interpretation of our findings relates to the recent price developments in the EU ETS.

5.1. Expectations and carbon pricing relevance

Investment decisions depend on companies' expectations, both regarding the carbon price level and climate policy in general. *Ceteris paribus*, a carbon price floor may increase the average expected carbon price level either by constraining expected price fluctuations at the bottom or by directly exceeding *ex ante* expected carbon prices. Importantly, a price floor may also affect climate policy expectations in general as – in combination with its level and trajectory – a price signals a regulator's overall commitment to ambitious climate policy.[21] The extent to which *ex ante* expectations are adjusted under a price floor should determine whether and how much companies alter their investment plans.

Extending our analysis shows that respondents expecting higher carbon prices are more likely to increase their investment level under a high price floor relative to a low price floor.[22] Driven by their comparably high expectations, those companies might have already identified, but not yet implemented, additional low-carbon investment opportunities that only become profitable under a high price floor. We find no such effect for companies that expect a price floor in the year 2030. We also find that climate policy expectations are decisive for

[20] A detailed description of variables is provided in Appendix A.4. Appendix A.5 shows the regression outcomes.

[21] Implementing a high floor signals a high ambition, a low floor the opposite. Note that, while we generally assume that a price floor increases the expected ambition level of climate policy, a very low price floor might communicate unwillingness to adequately address climate change.

[22] We extend our regressions by (i) the expected EUA price for 2030 and, (ii) a proxy for climate policy ambition.

expected carbon prices (see Table A.2 in Appendix A.4).[23] Expecting a German price floor by 2030 leads to higher expected EUA prices of EUR 8 on average. Less robust findings indicate that expecting a more ambitious climate policy raises price expectations by EUR 5 to 6. Assuming that climate policies influence carbon prices, and not vice versa, would suggests a causal impact. Examining how climate policy expectations form is beyond our scope. Yet, a link between the credibility and coherence of adopted climate policies, and price expectations, is apparent.

Though our sample selection presumes that carbon prices are generally relevant for investment decisions, structural and company specific factors may lead to important differences between companies. Indeed, extending our empirical analysis reveals that companies, for which a carbon price is highly relevant for investment decisions, are more likely to increase their investment level under a high price floor.[24]

5.2. Portfolio adjustments

Each company's reaction to a carbon price floor differs in how they adjust their investment portfolio. While some companies increase low-carbon investment or abolish fossil investment as envisaged, there is a risk that others move their fossil portfolio to an unregulated area (carbon leakage). Responses indicate that a higher investment level unambiguously involves a portfolio extension towards low-carbon investment. Of those maintaining their investment level, half also keep their investment portfolio unchanged, while the other half replace fossil—with low-carbon investment (see Appendix A.2). Unchanged investment either indicates that the actual price floor is in line with expectations (see Section 5.1), or that carbon pricing is not relevant for investment decisions. Decreased investment levels indicate more abolished fossil than added low-carbon investment. In our survey we explicitly ask for investment in Germany, so carbon leakage might be another potential explanation for low investment (Fowlie, 2009). Notably, industry companies receiving an electricity price compensation report particularly reduced investment levels. The comparably low investment in innovation in these companies suggests rather inflexible business models, which makes them prone to carbon leakage.

Examining the emerging literature on *ex post* analyses about carbon leakage provides only weak empirical evidence supporting the carbon leakage hypothesis (Branger and Quirion, 2014; Koch and Basse Mama, 2019),[25] although most *ex ante* modeling studies analyzing uneven climate policies predict an increased leakage risk of 5–20 percent (Branger and Quirion, 2014). Those analyses were conducted during phases of low EUA price levels. In light of our analyses, however, those results might not be valid for higher carbon prices, particularly because EU ETS companies that are at risk of leakage[26] have been generously compensated (Martin et al., 2014a). Policy makers may expect that companies declaring decreasing investment would probably demand additional or at least continued compensation if a compulsory high price floor was introduced.

5.3. Policy implications of high but still volatile carbon prices

The prices of carbon certificates in the EU ETS reached almost EUR 100 in early 2022, and thus increased tremendously since the dissemination of the survey in late 2018. Such price levels have been unexpected by the survey participants (and admittedly also by the authors of this study). Besides higher prices, the EU discusses to reduce the number of carbon certificates with the "Fit for 55" package, while the green new deal, and the European Climate Law, further underline increased climate ambitions of EU member states. All this entails the questions whether a high price floor would be still a beneficial design component for the EU ETS, and whether this affects implications of this study for policymakers and the academic debate more generally. To be sure, high prices are no insurance on their own. Early March 2022, saw a 30% drop in prices in just one week, associated with the war in Ukraine.

Both current and expected prices are key for investment decisions. A price floor, apart from potentially increasing the carbon price level, is supposed to stabilize expectations. A price floor would thus only become obsolete, when assuming that price expectations have now stabilized at current high levels (and additionally, when assuming that current price levels are sufficiently high in the first place). We may indeed suspect that average expected prices for 2030 or 2050 have increased compared to the levels stated in our survey, as status quo prices generally affect price expectations. However, the expected price level of individual investors, depends, first, on their assumed underlying explanations for high prices, and, second, whether this explanation suggest high prices also in the future. As we saw in March, 2022, prices can change downward suddenly. There are different attempts to explain the currently high prices, covering speculation of financial investors (Quemin and Pahle, 2021), adjusted climate policy expectations, the latest adjustment of the market stability reserve (MSR) in 2018, or additionally required emission certificates, e.g. due to more coal being used in consequence to high gas prices. In fact, these explanations are not mutually exclusive, and may thus all contribute to current high prices.

Each explanation has different implications for (the stability of) expected prices. For example, a price driven by speculation appears generally less stable than higher perceived policy ambitions, while an explanation along higher gas prices depends on assumptions about the future gas supply. Or, while the 2015 version of the MSR had no noticeable impact on EUA prices and only increased the short-term scarcity of allowances, we have seen gradually increasing EUA prices since the reform in 2018, which additionally reduced the long-term cap (see Perino, 2018). However, whether the higher prices can exclusively be attributed to the MSR, or whether they are caused by other factors or reform elements, is subject to ongoing academic and political debates. Moreover, the MSR does not but prevent collapsing or fluctuating prices in the future. Overall, the future price level thus remains generally uncertain, and we think that this uncertainty would be reflected in the responses if we repeated our survey today, despite the average price being on a higher level. This suggests that a carbon price floor, maybe even higher than in our "high price floor scenario", would still be a valuable extension to the EU ETS.[27] However, policymakers need to be

[23] To further explore the link between carbon price and climate policy expectations, we use a simple OLS model to regress the expected EUA price for 2030 on policy expectations and company types. Specifically, we control whether the respondents expect a higher level of climate policy in 2030, the implementation of price floor in 2030 and the achievement of the 2030 targets, respectively for Germany, the EU and the G20. The definitions of the included variables and the regression results are provided in Appendix A.4.

[24] We add dummy variables to our previous regression for companies that (i) report a high relevance of EUA prices for investment decisions and (ii) are regulated under the EU ETS.

[25] In fact, Koch and Basse Mama (2019) find no statistically significant increase in foreign direct investment outside the EU ETS for regulated multinational firms in Germany. However, they find that the number of subsidiaries increased for EU ETS companies as well as foreign direct investment for a subset of less energy- and emission-intensive companies that only represent a small share of regulated emissions.

[26] According to EU definition, companies are under official carbon leakage risk if their carbon intensity and their trade intensity are above 5 and 10 percent or if either is above 30 percent. The primary reason why industry emissions are exempted from auctioning is because they exceed the 30 percent trade intensity (Martin et al., 2014b). Alternatively, carbon leakage could, for example, be addressed by border tax adjustments (Branger and Quirion, 2014).

[27] Note that the coalition treaty of the current German government envisages introducing a national price floor of EUR 60 should EUA prices collapse below that level (German Government, 2021).

careful that a price floor trajectory does not exceed its optimal level—even if this is difficult to determine ex ante. Eliciting which carbon price trajectory would be optimal from the perspective of companies could be an interesting avenue for further research.

That said, generalizing findings of our study for the current EU ETS under a high price regime, or for other cap-and-trade systems remains challenging. From our study, we know that introducing a floor price along expected prices that (only) serves as a downward price insurance, would not necessarily have a strong effect on investment decisions. We see two potential explanations, namely that (i) a price increase from EUR 20 to EUR 40 from 2020 to 2030 would have simply provided insufficient economic incentives to increase low-carbon investment, or that (ii) firms perceived our low price floor scenario as hampering the credibility of climate policy, which offset a potential price effect. Although we cannot infer how price floors would alter firm investment within different contexts, we at least know that introducing a price floor along low expectations risks having little impact on investments. That a high price floor above expected prices significantly affects investment decisions is less surprising, as such a price floor would certainly alter the economic conditions. If politically feasible, policymakers in ETS operating at very low price levels considered insufficient might thus aim to introduce price floors above expectations. Otherwise introducing a low price floor, and ratcheting it up later, remains the only option.

CRediT authorship contribution statement

Nils Ohlendorf: Formal analysis, Investigation, Data curation, Writing – original draft, Visualization, Conceptualization, Methodology, Writing – review & editing, Project administration. **Christian Flachsland:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Gregory F. Nemet:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition. **Jan Christoph Steckel:** Conceptualization, Methodology, Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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Chapter 3

The Political Economy of Coal Phase-Out: Exploring the Actors, Objectives, and Contextual Factors Shaping Policies in Eight Major Coal Countries

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Original research article

The political economy of coal phase-out: Exploring the actors, objectives, and contextual factors shaping policies in eight major coal countries

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ABSTRACT

Political economy factors are key to explain why some countries keep expanding their coal capacity. Yet, comparable cross-country evidence is scant. We consult 123 energy experts for eight major coal countries through an online survey, to assess which political economy factors affect coal-related policies. Regardless of the political or economic system, we find that the ministry for energy, the head of state and the ruling party are consistently the most important political actors, while utilities and mining companies are the most influential economic actors. Generally, other societal actors are the least influential. Economic growth, electricity system stability and low electricity costs are very relevant objectives the major arguments of pro-coal actors. The most relevant contextual factors are the influence of the power sector and structure of the power market. Actors, objectives, and contextual factors related to the environment are consistently less important. The insights of this study help identify entry points for politically feasible policies to phase-out coal.

1. Introduction

With a global operating capacity of 2,067 GW in mid-2021, coal remains the largest source of electricity and global greenhouse gas emissions [1–3], and further committed coal emissions may seriously jeopardize the targets of the Paris Agreement [4–6]. Fortunately, between 2015 and 2020 the annual capacity of completed coal power plants and those under construction both halved [7]. The planned capacity even decreased by 72 percent, and many countries, namely the US, members of the European Union and the UK continuously reduce their coal capacity [7]. Despite these positive trends, the net global coal capacity continues to increase each year, mostly driven by China and selected other countries [7].

Why are some countries persistently deploying new coal-fired power plants, despite the risk of stranded assets [8], adverse impacts on health and the local environment [9], increasingly salient climate change impacts [10], and decreasing costs of alternatives, i.e. renewable energies (REs) [11]? Several case studies suggest a pivotal role of incumbent actors on the political economy of coal [12–19], while others describe the strategic behavior of incumbent actors in transition processes of energy systems in general [20–23]. Yet, heterogeneous analysis frameworks and methodologies render deriving broader conclusions challenging. By conducting a cross-country survey and using a political economy meta-framework, in this paper we aim to provide comprehensive, comparable and robust evidence of factors affecting political decision-making processes that favor coal in eight major coal countries. We assess the importance of different political, economic, and other societal actors, and which socio-economic, political and environmental objectives and contextual factors guide them. Moreover, we assess corporate political strategies and pro-coal arguments.

We conduct a survey with experts for China, India, Indonesia, Vietnam, the Philippines, Turkey, South Africa and Japan, each of which has substantial current, recently deployed and prospective coal capacities. This selection is guided by the idea that countries with an established and powerful coal industry face significant political economy obstacles to a timely coal phase-out; we aimed to select those countries with potentially the most difficult coal phase-outs ahead.

We conducted an online survey with 123 energy experts to obtain comparable country-specific knowledge on the respective political economy. Conceptually, our analysis is based on a political economy meta-framework that has been specifically developed for cross-country comparisons [19]. This framework assumes that actors influence political decision-making processes within a given country context, with decisions being guided by multiple objectives. We further specify the applied tactics of pro-coal companies by integrating the well-established corporate political strategy (CPS) taxonomy by Hillmann and Hitt [24]

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that distinguishes between the financial incentive, information and constituency building strategies. In addition, we elicit which pro-coal arguments are used in communication with policy makers and the constituency.

We find that political actors, and in particular, the ministry for energy, the head of state and the ruling party, are consistently the most important across the sample. Economic actors are the next most important actor group, especially utilities and mining companies, even though responses strongly deviate between countries. Other societal actors are least important, except for small elite groups and industrial associations. Analyzing objectives and contextual factors shows a pivotal role of economic growth; it is the single most relevant objective and third most relevant contextual factor and thereby, both a goal and driver of coal deployment. Yet, the most relevant contextual factors are the power sector's influence on policy making and the structure of the power market. Actors, objectives, and contextual factors related to the environment are consistently less important. Lobbying and installing representatives in public positions are the most relevant tactics of pro-coal companies. Pro-coal actors argue that coal ensures a stable electricity supply, provides cheap electricity, is necessary to satisfy a growing energy demand, and that it fosters economic growth. Finally, we cluster responses by country and show distinct patterns of survey responses for Japan and China.

With our cross-country survey research design, we respond to the regularly voiced call for comparative research designs and innovative methodological approaches [25–28], particularly towards comparative climate change politics [29–31]. These have a higher external validity than single country studies and thus allow us to draw broader conclusions. Eliciting expert knowledge via surveys on a well-researched topic has a number of advantages over other comparative methodologies. For instance, traditional literature synthesis methods, such as systematic reviews, are constrained by available studies using different research approaches. By contrast, responses to identical survey questions as used in our study provide directly comparable evidence.

We proceed by first embedding our study in the academic literature, then describing our conceptual approach and methodology, and thirdly reporting our results. Finally, we discuss our findings and conclude.

2. Literature

Our study adds to a body of comparative literature on the political economy of climate policy and specifically coal. Diluiso et al. [32] systematically review studies on historical coal transitions. They find that rising production costs for coal, falling prices for alternative energies, and local environmental concerns have been the most important drivers of historical coal transitions, while structural change transformations in coal-dependent regions, and overall rising unemployment, are the greatest challenges. Using macro data, Lamb and Minx [33] analyze national constraints for climate policy legislation and find that a cluster of 'coal-dependent countries' is characterized by moderate adoption of climate policy legislation, existing fossil fuel subsidies, and fragile institutions that are exposed to corruption. Others focus on coal transitions [34], the global coal market [35], and the persistence of coal facing the trade-off between energy and environmental politics [36].

Our study relates to several fields and disciplines. The emerging field of sustainability transitions builds on a rich body of concepts [37,38], of which the multi-level-perspective being a framework that is frequently applied [39]. Actors enabling regime stability have been theorized by the concepts of regime resistance [20], and institutional strategies of incumbent actors [21]. Related approaches rooted in economics also show that vested interests have an incentive to block the adoption of new technologies [40,41] to protect their political power [42]; further, democracies have a greater ability to fend off such vested interests than autocracies [43]. Political scientists analyzed the political power of influence groups, focusing on party patronage, lobbying expenditures, and campaign finance, and corruption in the climate policy context [44–48]. Several studies focus on historic energy transitions [49–51]. They find that countries managing to resist powerful vested interests more easily adopt alternative clean energy sources.

Different concepts describe conditions for energy system transitions including the role of politics. For example, emphasizing the role of government politics in sociotechnical transitions, several scholars proposed the typology of ideas, institutions and interests as explanatory factors for the adoption of policies that lead to (energy) system innovations and sustainability transitions [52,53]. Others argue that, whether effective and stable climate policies are implemented, depends on the distribution of costs and benefits between the regulated actors, and the public [54]: in 'Stiglerian settings', few regulated actors benefit from regulation and costs are dispersed over many, whereas 'Olsonian settings' are characterized by diffused regulatory benefits and concentrated regulatory costs. The concept of carbon lock-in provides an explanation for inaction, by describing how the interaction between technological systems and governing institutions can establish fossil fuel based energy systems, which hinder the deployment of economically and environmentally advantageous low-carbon technologies [55]. This study conceptualizes policy adoption by the actors-objectives-context (AOC) political economy meta-framework for (see next section for description) [19].

The role of actors and actor coalitions for the political economy of coal has been at the center of multiple country case studies [56]. For example, coal politics in the Czech Republic is characterized by two opposing coalitions of industry and environmental actors. Policymakers, however, have heterogeneous beliefs, and thus participate in both coalitions [57]. A sustained use of coal in Poland is fostered by a coalition of actors between coal corporations, unions, parts of civil society and the government [58]. Actors from civil society and local communities in Bangladesh, in turn, lobby against coal [59].

Policy goals related to coal in different country contexts have also been subject of ample research. In Poland, actor coalitions promote continued coal use to prevent loss of businesses, structural change, rising energy prices, import dependence and unemployment in coal-dependent regions [58], while policymakers link coal with the idea of national modernization [60]. Arguments against coal in Poland are uneconomic coal mining, unavoidable energy infrastructure investments, rising air pollution levels and pressure from the European Union [58]. The government of the Philippines outlined affordability, access, and reliability of electricity as key for national development to justify coal use, while opponents argue that other energy sources would better promote the goals of energy justice and energy democracy [61]. Resistance to coal power plants in Bangladesh is narrated via the topics of environmental degradation, land grabbing, corruption and crony capitalism [59]. Regarding different regions of the US, some stakeholders are mostly concerned about employment implications of an energy transition, while others worry about rising energy costs and their impacts for low-income residents [62].

Resistance by incumbent actors and coalitions to coal transitions and related discourses are further research foci. The regime resistance concept [20] has been applied to case studies on South Africa's electricity system incumbent Eskom opposing the deployment of REs [23], while 'strategies of incumbency' of shale gas fracking and nuclear power regimes were identified in the UK energy system [22]. Others have assessed how incumbent firms and their industry organizations employ material, institutional and discursive power [63]. Discursively influencing public narratives is a pivotal strategy by incumbent actors in the fossil fuel industry [64]. Large-scale energy projects are frequently justified by grand narratives, such as promoting economic growth, securing energy supply, modernizing energy service provision, and transitions to more sustainable energy systems [65]. Regarding coal, decision makers and energy policy stakeholders dominate the discourse that hinders the emergence of new narratives [66]. Yet, coal phase-out narratives may change over time with changing societal contexts [67]. For example, narratives linked to coal in German parliamentary debates in the last 70 years have switched from economic prosperity and energy security towards energy transition, coal phase-out and renewable energy expansion [68]. Still, the recent coal phase-out discourse was dominated by coalitions of core actors emphasizing risks and threats [69]. By contrast, opponents to coal mining in the Czech Republic are found to be an inhomogeneous group that employs different protest tactics using a complex set of narratives [70].

The above contributions demonstrate that actors and their specific goals affect coal politics, contingent on the respective country context. The reviewed literature also suggests that a more detailed understanding of how actors promote pro-coal policies, and which arguments they use, seems necessary. Yet, the application of different conceptual frameworks, and the partially contradicting findings, make it difficult to create generalizable insights based on the existing literature.

Our study aims to fill this gap with a comparative approach that builds on a consistent cross-country analysis. More specifically, this paper envisages providing quantitatively comparable cross-country evidence from surveying energy experts on political economy determinants affecting coal-related policies. The development of the survey questions is guided by an energy policy meta-framework, and the established CPS taxonomy. Analyzing responses to homogeneous survey questions allows identifying which political economy factors are relevant across countries, and which are idiosyncratic to specific contexts, and thus to generate broader insights. We also address calls for a new research agenda on politics of low-carbon transitions that, among others, highlights the relevance of the interplay between actor preferences and policies, and the role of contexts [71].

3. Conceptual approach

We apply a political economy meta-framework that has been specifically developed for energy policy analyses across different countries [19]. In the framework, *political actors* influence policy making, while being themselves influenced by *societal actors*.[1] Both, *political actors* and *societal actors* are guided by several socio-economic *objectives*. The ability of *political actors* to influence policy making, and of *societal actors* to influence *political actors*, is determined by country-specific *contextual factors*. The actors-objectives-context (AOC) framework has recently been applied to case studies based on semi-structured interviews, for example in Vietnam [72], India [73], Indonesia [74] and the Philippines [75]. A collection of 15 case-studies using the AOC framework has been recently published in an edited volume [76], while major insights from the book have been condensed to a research article [77]. The generic actor-centered framework design allows for conceptual extensions and for comparisons of countries with different political systems and institutional structures.

We exploit this feature and combine the framework with the established CPS typology of Hillmann and Hitt [24]. Applied to the AOC framework, the CPS further specifies the influence channels of *societal actors*, and in particular pro-coal companies, on *political actors*. It distinguishes between three strategies that are applied by companies with the goal of influencing policy makers, namely (1) financial incentives, (2) information and (3) constituency building. Each strategy comprises distinct tactics that either directly target political decision makers (information and financial strategy) or the public (constituency-building strategy).

The generic analysis categories from both frameworks correspond with frequently used objects of analysis as discussed in the previous section. These comprise research on the role of different actors, which objectives drive them, how contextual factors within countries affect their goals and actions, but also which strategies they deploy and which arguments they use. Formulating survey questions and response options based on these generic analysis frameworks allow us to compare responses across different country contexts.

4. Methodology

This section first provides background on the role of coal in the countries analyzed. It then explains how we obtained our sample based on an online survey. Finally, it discusses our empirical approach to analyzing this data.

4.1. The sample

Our sample includes China, India, Indonesia, the Philippines, Vietnam, Turkey, South Africa and Japan. These countries were selected as they have a large current, recently deployed and prospective coal capacity which is likely to lock-in future carbon emissions. The selected countries' coal capacities are all among the global top 20 in early 2020 in terms of each of the following dimensions: (1) current operation, (2) newly operating since 2015, (3) under construction, and, (4) announced, pre-permitted and permitted. Jointly, these eight countries operate 1402 GW (69 percent of total global capacity), have recently built 325 GW (87 percent), are currently constructing 174 GW (87 percent) and plan an additional 227 GW (76 percent) of coal capacity in the year 2020 (see Fig. 1). China leads in all dimensions, most frequently followed by India. While the remaining six countries comprise less than 10 percent of currently operating global coal capacity, they add around 10 percent of recently built capacity, 20 percent of capacity under construction and comprise roughly 30 percent of planned capacity. The energy systems in each country largely depend on coal, with shares of generated electricity between 31 percent in Japan and more than 86 percent in South Africa for the year 2019. REs in most countries contribute less than 15 percent capacity [78].[2]

4.2. Survey data

We analyzed survey responses of 123 energy policy experts obtained between September and November 2020. Focusing on *policies affecting new coal-fired power plants*,[3] the survey elicits the *influence* or *relevance* of different political and societal actors, objectives, contextual factors as well as tactics and arguments of pro-coal actors using a five-point Likert Scale from 'Very low' to 'Very high' (see Supplemental Information (SI) for the original questionnaire). The ten selected survey questions thus reflect the structure of the frameworks by Jakob et al. [19] and Hillman and Hitt [24]. The initial response options emerged from findings of previous country case studies on coal and were refined during multiple iterations. To ensure a common understanding of questions and response options and thus minimize measurement error, the survey was discussed and iterated within the author team, and pre-tested by eight external energy experts, until all ambiguities had been resolved.

We attempted to identify energy policy experts with a holistic country-specific knowledge on coal politics. We identified the experts based on a systematic screening of empirical academic publications related to energy policy in each country and personal recommendations of survey participants. Based on keyword search merging findings from *Web of Science* and *Scopus*, we identified 3703 potentially relevant studies. Screening title and abstract provided 178 relevant studies,

[1] To receive more insightful survey responses, we create the subgroup of economic actors as part of societal actors. Economic actors are defined by operating on the market, while the remaining other societal actors are not.

[2] The Philippines are not covered by the BP [78] dataset. According to the Department of Energy of the Philippine government [79], in 2019 coal is used to generate 55 percent electricity and REs 21 percent.

[3] In the survey we define 'new' as those recently built (2015–2019), currently under construction and planned.

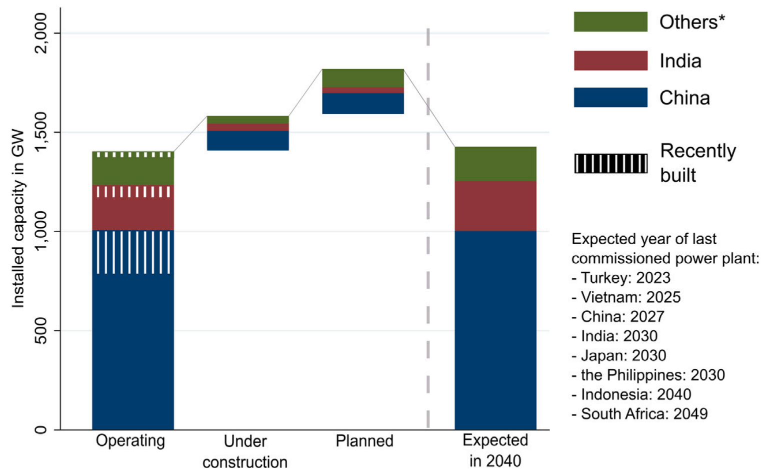


Fig. 1. Coal Capacity Overview.
Notes: The figure shows the coal capacity of our sample that is operating, under construction and planned in the year 2020 [80]. Recently built power plants comprise facilities that were commissioned since 2015. Based on median survey responses, we also show the expected coal capacity in 2040 and the expected year of the last commissioned power plant. It must be noted that only two-thirds of respondents replied and that expectations deviate greatly.
*Others comprise Indonesia, Japan, South Africa, the Philippines, Turkey and Vietnam.

of which 69 were included based on the full text. We obtained the final sample of 101 studies after identifying additional literature via a forward search (citing references) for the entire initial sample, and a backward search (cited references) for the most relevant and recent publications using *Google Scholar*. We primarily focused on researchers who published empirical work on energy policy after 2010, as we expect these to have detailed in-depth knowledge, and no incentive to provide responses that depart from their best interest. Generally, we disseminated the survey to all study authors. To reduce coverage error by including survey responses based on outdated or limited information, we asked respondents to answer only when feeling sufficiently knowledgeable. Practitioners who were explicitly recommended by the researchers identified, or stem from the academic network of the author team, complemented our selection of experts. Each expert received one initial survey invitation and one reminder via email.

The final sample includes complete (incomplete) responses of 110 (123) energy experts.[4] Most are academic researchers (58 percent of total) or from NGOs (22 percent). The remainder work in consultancies (6 percent), politics (5 percent), international organizations (4 percent), or hold other occupations (5 percent).[5] The responses by country are slightly uneven: India (23 percent), Japan (17 percent), China (14 percent), the Philippines (11 percent), Indonesia (10 percent), Turkey (10 percent), South Africa (8 percent) and Vietnam (8 percent). The SI contains the questionnaire and further details on the survey development and the expert selection strategy.

4.3. Empirical assessment

We focus on responses that are of consistently high or low relevance despite institutional and other differences between countries. To identify particularly homogeneous responses, we assess the spread of the mean responses by country and the standard deviation of all survey responses. We also discuss country-specific outcomes that strongly deviate from the mean, although detailed country-specific analyses are beyond our scope. Text responses complement the quantitative analysis of survey data. The robustness of our findings is briefly addressed in the discussion and more extensively in the SI.

Furthermore, we try to identify country groups and general patterns in the responses. First, we conduct a cluster analysis to identify potential groups of countries with particularly similar response patterns. We apply a k-means algorithm on the mean responses by country including (i) all survey questions, and (ii) different combinations of survey questions to identify between two and four clusters [81]. To test whether the findings are robust, we implement the analysis using five different (dis-)similarity measures for continuous variables and also conducted a k-median analysis, providing largely similar results. Second, we analyze highly correlated survey responses to identify response patterns that apply over all countries. We correlate the mean responses by country of all 77 survey response options and subsequently thematically group the response pairs among the highest 1 percent of absolute correlation coefficients.

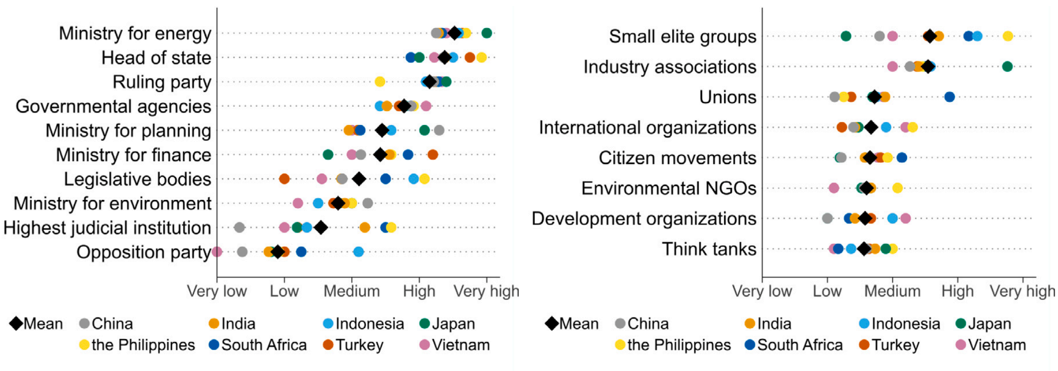
5. Results

This section first discusses the survey results along three dimensions: (i) actors, (ii) objectives and contextual factors, and (iii) tactics and arguments used by pro-coal actors. Figs. 2–6 show the mean survey responses for each country and over the entire sample.[6] Second, we identify country clusters that arise from the answers and analyze highly correlated survey responses.

[4] We successfully sent the survey to 307 experts in total. The survey was opened 162 times. In 35 instances, the respondent immediately dropped out, with roughly half reopening the survey at a later point in time. After removing four double entries (likely due to connection problems), we obtain 123 unique responses to the first survey question. With 13 participants dropping out during the survey, we receive 110 complete entries. Complete entries describe respondents that finalized the survey, which does not imply a reply to all response options.

[5] Other occupations comprise media (2 respondents), think-tanks (1), private foundations (1) and the private sector (1).

[6] Table A.3 in the SI provides additional descriptive statistics, such as the number of responses, the standard deviation and the country spread, i.e. the difference between the lowest and highest country mean. While the country spread only shows the variation of responses between countries, the standard deviation across the sample, in addition, considers within country variation and is thus the strongest indicator of consistent outcomes. Table A.4 in the SI provides the mean responses by country and thus conveys the same information as Figs. 2–6.



(a) Political Actors (b) Societal Actors

Fig. 2. Political and Societal Actors.
Notes: The figures show the influence of political (a) and societal (b) actors on political decisions regarding new coal-fired power plants for each country and the mean across countries. The responses range from 'very low' to 'very high' and are sorted from the most to the least influential mean values.

5.1. Actors

We define three basic categories of actors. *Political actors* are actively involved in political decisions and the organization of the respective states. *Economic actors* and *other societal actors* are outside such formal decision-making structures. *Economic actors* operate on the market, in contrast to *other societal actors*.

Across countries, selected executive branches of the government are highly decisive for new coal power plants, while societal actors have significantly less impact on political outcomes (see Fig. 2).

In most countries, the energy ministry, the head of state, and the ruling party have substantial influence, while opposition parties play a minor role. Hence, actors in the highest governmental positions and their executive branches for energy have the relatively greatest influence on coal-related policy decisions, regardless of the different governmental systems and institutions. In contrast, the environmental ministry is assigned a consistently low to medium influence. Reflecting differences in the institutional set-up of countries, planning and finance ministries as well as legislative bodies are highly influential in some countries. For example, in China, the National Development and Reform Commission is responsible for economic planning including the national energy policy and the preparation of the Five-Year-Plan. In some countries including India, South Africa and the Philippines, the highest judicial institution has a relatively higher influence, which outlines the occasionally high authority of courts over coal deployment.[7]

In contrast to political actors, responses for the most important societal actors are less consistent. For example, the strongly varying influence of small elite groups across countries may reflect different forms of governance as well as levels of institutional quality. The influence of trade unions in South Africa and industrial associations in Japan is particularly notable. In contrast to findings in the 'just transition' literature, focusing mostly on developed countries, unions do not play a major role in our sample. Other societal actors are not very influential either, especially when compared to political actors, although text responses for Japan, the Philippines and Turkey suggest an increasingly prominent role of environmental NGOs.

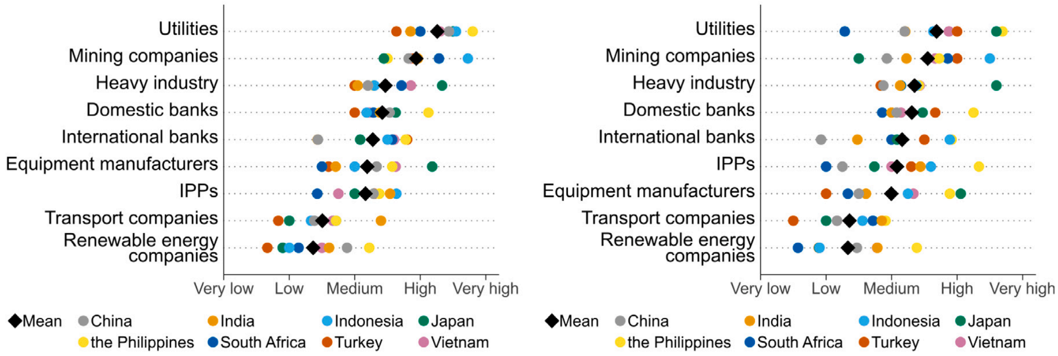
Across countries, and regardless of whether publicly or privately owned, utilities and mining companies are the relatively most influential economic actors, while transport and renewable energy companies are the least influential (see Fig. 3). Economic actors (public and private alike) differ strongly in their influence by country, which reflects diverse institutional settings in their respective energy sectors. Some country particularities stand out: for example, in Japan equipment manufacturers and heavy industry seem to be particularly influential, while mining companies are particularly strong in Indonesia and South Africa, where mining and coal exports play an important role. The influence of the railway sector on coal in India, as frequently reported in the literature [73], is also notable. Generally, heavy industry, domestic and international banks, equipment manufacturers and independent power producers (IPPs), have medium to high influence.[8]

We elicit the overall influence of each actor group to complement the previous findings, and assess the influence of international and sub-national political actors relative to the domestic political actors (see Fig. 4). We find that political actors are most important for coal-related policy decisions, which is in line with previous evidence on coal transitions [32]. However, public or private economic actors may be equally important, depending on the country, and whether or not its economy and energy system are liberalized. Since public economic actors are directly interacting with political actors, substantial influence is to be expected. However, it is striking that private economic actors may be equally influential although one might expect a relatively greater distance to policy makers. We will further discuss tactics of (public or private) pro-coal actors in influencing coal-related policies below. Other societal actors are overall least influential.

In comparison to national political actors, some sub-national actors may be highly influential, while the influence of international actors is consistently medium. For sub-national political actors, we see a particularly high influence in China and India, followed by Indonesia and

[7] Text responses indicate additional influential ministries, such as the Ministry of Public Enterprises in South-Africa, or the Ministry of Commerce in India, and other influential individuals. Others elaborate the country-specific roles of single elicited actors, or refer to societal, economic or sub-national actors that are subject of subsequent survey questions.

[8] However, not all response options apply to each country. This requires a particularly careful interpretation. For example, Japan and the Philippines have no public energy companies, while private companies are less prevalent in Vietnam and China. In such cases, we asked respondents to select a 'not applicable' response option, which lead to numerous missing entries. However, some respondents replied irrespective of whether the response option applied to their country, either assigning a low influence, or disregarding a difference between public and private economic actors. We discuss potential correlations between responses and missing entries later and in the SI. Text responses furthermore indicate that horizontally or vertically integrated companies may cover multiple response options, whereas other respondents suggested further distinctions to enable them to provide more specific responses.



(a) Public Economic Actors (b) Private Economic Actors

Fig. 3. Economic Actors.
Notes: The figures show the influence of private (a) and public (b) economic actors on political decisions regarding new coal-fired power plants for each country and the mean across countries. The responses range from 'very low' to 'very high' and are sorted from the most to the least influential mean values.

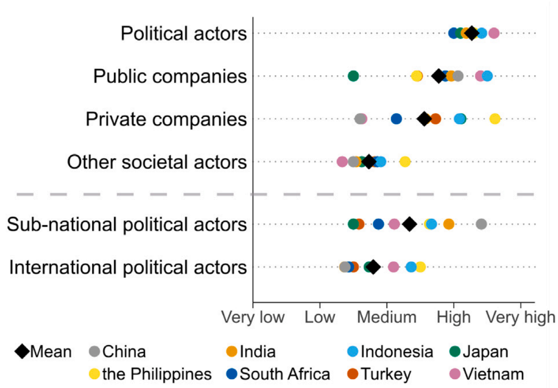


Fig. 4. Actor Groups and Governance Levels.
Notes: The figure shows the influence of actor groups (upper part) and governance levels (lower part) on political decisions regarding new coal-fired power plants for each country and the mean across countries. The responses range from 'very low' to 'very high' and are sorted from the most to the least influential mean values, respectively for the upper and the lower part. Remark: we elicited the influence of the most influential sub-national and international political actors relative to national political actors.

the Philippines, while they are least influential in Turkey and Japan. In both China and India, regional or provincial governments ultimately rely on revenues and employment generated by the coal industry [14, 73], although the institutional organization of each country is substantially different. International political actors are most influential in the emerging economies of South-East Asia, namely the Philippines, Indonesia and Vietnam. For example, in Vietnam international development organizations play a particularly large role [72].

5.2. Contextual factors and objectives

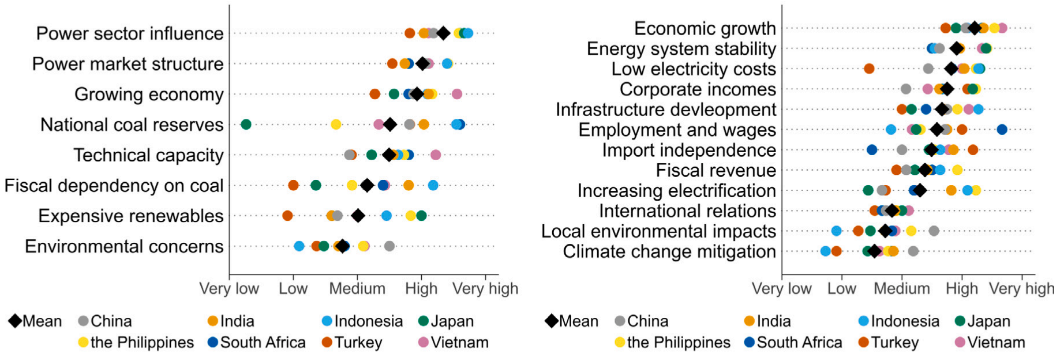
It is striking that both the power sectors's influence and market structure seem to have the greatest relevance for the political economy of coal when averaged over all eight countries. This is followed by economic growth (see Fig. 5). In all countries environmental concerns consistently ranked quite low, however there are stark country-related differences for other contextual factors. Existing coal reserves are particularly relevant in Indonesia or South Africa, and in Indonesia this aligns with a fiscal dependence on coal. The costs of alternatives, i.e. REs, ranks high in some countries (e.g. Japan and the Philippines), but is of low relevance in others (e.g. Turkey).

From the perspective of objectives, the eight coal investing countries in our sample unanimously give a high priority to economic growth, energy system stability and low electricity costs (see Fig. 5). In contrast, environmental objectives including climate change mitigation rank lowest. The poorest countries in the sample (India, Indonesia and the Philippines) give a high priority to electrification. For Turkey, low electricity costs seem to be of lower importance, while employment and wages seem to be particularly relevant for South Africa. It has to be noted that contextual factors may in part influence the objectives, as, for example, the objective of increasing electrification will only be relevant in countries that lack a sufficient supply of electricity.

5.3. Pro-coal tactics and arguments

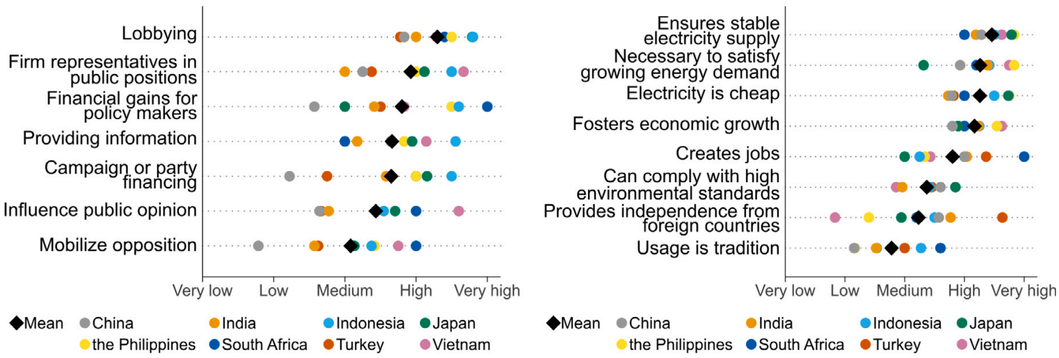
Lobbying, in our survey defined as formal and informal meetings, is consistently the most relevant tactic of pro-coal actors (see Fig. 6). This is particularly interesting, given that the finding applies to state-centered and market economies alike. This is the only finding consistent across all countries. The relevance of all remaining tactics varies strongly and has a pronounced country-specific pattern; for China, India and Turkey, the mean relevance of all tactics is medium, while it is high for all other countries (see SI). This suggests that there are country-specific differences in the overall relevance of pro-coal tactics as applied by pro-coal actors, as similar country-specific patterns are absent from other questions. Numerous missing entries, however, further complicate the interpretation (see SI for further discussion). Under these circumstances, it is difficult to unambiguously identify particularly relevant CPS. Yet, there is a slight tendency suggesting that the information strategy comprising lobbying is most relevant, while the constituency building strategy is least relevant.

Pro-coal actors almost unambiguously argue that coal ensures stable electricity supply, is necessary to satisfy growing energy demand, is cheap and fosters economic growth. Only in Japan, being the only industrialized country, is this different as its energy demand is not growing. By emphasizing economic growth, cost and security aspects, pro-coal arguments thus seem to resonate with the most relevant objectives that we identified earlier. These arguments bring techno-economic advantages of coal to the fore. Independence from foreign countries and jobs also seem to be relevant in some countries. Independence from foreign countries is particularly relevant for Turkey, but not in Vietnam, while the association between coal and jobs features most prominently in South Africa.



(a) Contextual Factors (b) Objectives

Fig. 5. Objectives and Contextual Factors.
Notes: The figures show the relevance of contextual factors (a) and objectives (b) in political decisions regarding new coal-fired power plants for each country and the mean across countries. The responses range from 'very low' to 'very high' and are sorted from the most to the least relevant mean values.



(a) Pro-coal Tactics (b) Pro-Coal Arguments

Fig. 6. Pro-Coal Tactics and Arguments.
Notes: The figures show the relevance of pro-coal tactics (a) and arguments (b) in political decisions regarding new coal-fired power plants for each country and the mean across countries. The responses range from 'very low' to 'very high' and are sorted from the most to the least relevant mean values.

5.4. Country patterns and correlations

We extend our descriptive analysis by identifying country clusters and analyzing correlations between survey responses.

The cluster analysis shows whether individual countries or country groups provide systematically different responses to others. We apply a k-means cluster algorithm to (i) all survey responses, (ii) responses to the questions on actors, and (iii) responses to the questions on objectives, contextual factors and arguments reflecting the country background (see Table 1).[9]

We find that Japan and China consistently constitute individual clusters.[10] India and South Africa are also consistently in the same cluster, though never exclusively, and group with varying other countries. With four clusters, and considering all survey questions, we obtain a cluster of South-East Asian countries of Vietnam, the Philippines and Indonesia, while Turkey joins India and South Africa.

To better understand why Japan and China build their own clusters, we assess which of their survey responses deviate most strongly from the sample mean. Deviations by Japan stem from responses on objectives and contextual factors that are linked to its higher economic development level, its privatized energy sector and its lower involvement in coal mining. Japan is the only industrialized country in our sample. Objectives, such as increasing electrification, or infrastructure development, and the corresponding pro-coal argument that coal was necessary to satisfy growing energy demand are hence less relevant than in other countries. Furthermore, Japan's coal-mining sector is negligible [82], which leads to a lower relevance of sub-national actors, mining companies, and consequently of the argument that coal would create jobs. In Japan (private) utilities, heavy industry and equipment manufacturers are particularly important, which is in line with previous research that shows their strong ties to policy makers [82].

China deviates from the other countries because of its state-centered economy, its political system, the substantial influence of provinces and the increasing relevance given to environmental factors. More specifically, in China, the judiciary plays no role for coal deployment, and neither do opposition parties, while the NDRC (National Development and Reform Commission) is of very high relevance. Difficulties to clearly distinguish between economic and political actors may also explain why numerous tactics of pro-coal actors have a below average relevance. International actors, such as banks, have a rather low impact, which corresponds with Chinas state-centered economy. China's

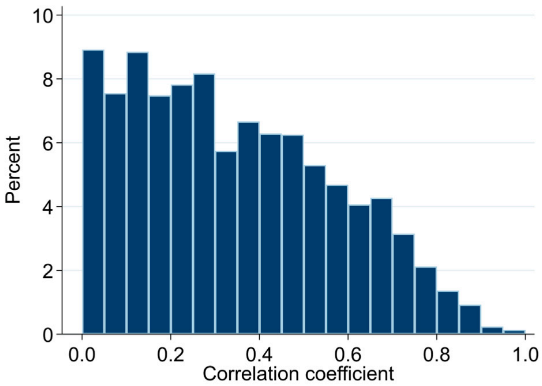
9 The survey responses on tactics are omitted due to many missing entries and the already discussed country-specific response patterns.

10 Japan also builds an individual cluster when conducting the k-means analysis with only two clusters.

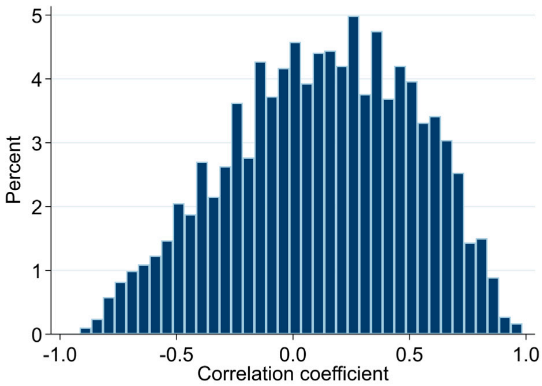
Table 1
Cluster analysis.

Included questions	Three clusters All	Actors	Country	Four clusters All	Actors	Country
India	1	1	1	1	1	1
South Africa	1	1	1	1	1	1
Turkey	1	1	1	1	4	1
Japan	2	2	2	2	2	2
China	3	3	3	3	3	3
Indonesia	1	1	1	4	1	1
the Philippines	1	1	1	4	1	4
Vietnam	1	1	1	4	4	4

Notes: The table shows results from a k-means cluster analysis with three (column 2–4) and four (5–7) clusters. For each number of clusters, we include *All* survey questions, survey questions on *Actors* (political, public and private economic, other societal), or related to the *Country* background (objectives, contextual factors, pro-coal arguments).



(a) Absolute Correlations



(b) Regular Correlations

Fig. 7. Correlation of Response Options.
Notes: The figure shows the percentage share of absolute (a) and regular (b) correlation coefficients between all 2926 pairs of survey responses grouped to bins of 0.05.

sub-national governments are key players, as they need to fulfill specific growth targets that incentivize coal investments. Finally, in contrast to most emerging economies, environmental concerns are increasingly important due to China's expanding middle class. The SI provides more details.

To identify structural political economy patterns that are valid across the sample, we calculate correlation coefficients between all survey response options. Fig. 7 shows the distribution of correlation coefficients across all response pairs in our sample. 62 percent of correlation coefficients are positive, the median of all absolute correlations is 0.31. The analysis focuses on the highest one percent of absolute correlation coefficients. We create three groups of thematically related response pairs to organize 16 of 29 response pairs with correlation coefficients between 0.86 and 0.98, namely 'powerful economic actors', 'growth and development' and 'environment' (see Table 2). The SI provides an extended version of the table with five groups covering all 29 response pairs.[11]

The group of 'powerful economic actors' underlines the link between economic actors and their policy impact. We find that a high power sector influence correlates with the tactic of lobbying, and a high relevance of private economic actors aligns with an increased relevance of corporate incomes. The remaining correlations link public or private utilities and equipment manufacturers with the power market structure, high cost of REs and the arguments that coal would provide a cheap and stable electricity supply. The correlations suggest that selected economic actors may be particularly successful in lobbying for a favorable cost structure in the power sector.

The group of 'growth and development' comprises correlations that link economic or energy growth with actors or objectives that are emblematic for developing countries. Economic growth as a contextual factor, objective or argument is positively correlated with relevant development- and international organizations, a lack of technical capacity and the goal of infrastructure development. The findings again underline the particular role of coal in the growing economies within our sample.

We furthermore group correlations between objectives and contextual factors related to the 'environment'. These include correlations between environmental concerns, climate change mitigation and local environmental impacts. Potentially, the relevance of environmental objectives increases with the perceived relevance of climate change impacts. Despite the low mean relevance, responses are medium to high in China, but low to very low in Indonesia. In China, for example, local combustion became a primary (environmental) concern in the last decade.

In summary, we obtained evidence that (i) selected economic actors may particularly affect the power sector (cost) structure, while using related pro-coal arguments, (ii) economic growth and its link to coal is of particular relevance for developing countries, and (iii) environmental vulnerability and public awareness are linked with environmental objectives. However, we emphasize that these are merely correlations, which, on their own, are not evidence of causality.

[11] The remaining response pairs are grouped under the labels 'data structure', comprising correlations deriving from the structure of our dataset, and 'unrelated', comprising correlations that refuse meaningful interpretations.

Table 2
Correlation coefficients.

Group	Type 1	Response option 1	Type 2	Response option 2	Correlation
Powerful economic actors	Actor	Utilities (private)	Argument	Coal ensures stable electricity supply	0.97
	Actor	Equipment manufacturers (private)	Contextual factor	Expensive renewables	0.96
	Actor	Utilities (public)	Contextual factor	Power market structure	0.95
	Actor	Equipment manufacturers (private)	Argument	Coal electricity is cheap	0.91
	Contextual factor	Power sector influence	Tactic	Lobbying	0.90
	Actor	Utilities (public)	Contextual factor	Expensive renewables	0.88
	Actor	Private economic actors	Objective	Corporate incomes	0.87
Growth and development	Objective	Economic growth	Contextual factor	Growing economy	0.90
	Actor	Development organizations	Argument	Coal fosters economic growth	0.89
	Objective	Infrastructure development	Contextual factor	Growing economy	0.88
	Actor	International organizations	Argument	Coal fosters economic growth	0.88
	Actor	Development organizations	Argument	Coal is necessary to satisfy the growing energy demand	0.86
	Objective	Economic growth	Contextual factor	Technical capacity	0.86
Environment	Objective	Local environmental impacts	Contextual factor	Environmental concerns	0.98
	Objective	Local environmental impacts	Objective	Climate change mitigation	0.93
	Objective	Climate change mitigation	Contextual factor	Environmental concerns	0.88

Notes: The table shows the highest percent of correlated survey response options sorted into the groups of 'Powerful economic actors', 'Growth and development' and 'Environment' and with descending correlation coefficients. An extended version of this table also covers the groups of 'Data structure' and 'Unrelated' (see Appendix A.7).

6. Discussion

We find that selected political economy factors consistently contribute to the ongoing deployment of new coal-fired power plants, despite the diverse political and economic systems of countries in our sample. In the following, we discuss further implications of our findings and limitations of our approach.

First, reducing the political influence of the power sector seems pivotal to eventually phasing-out coal. Across all countries, we find that economic actors (either public or private), and especially utilities, exert a substantial influence on coal-related policy decisions and the power market structure. Lobbying via formal and informal meetings is the most relevant tactic. Disentangling political and economic actors may thus be a way forward to overcome political resistance to energy transitions. Depending on the country context this may be subject to different challenges, for example when small elite groups are particularly influential. One option could be to unbundle horizontally or vertically integrated utilities as this could decrease their political power and generate further advantages, such as increased RE deployment [83–85].

Second, we find that the executive branches of governments are important for energy transitions. However, they need to consider numerous societal objectives, such as energy system stability, low electricity costs, and economic growth. Environmental objectives are in most countries of lesser importance, at least in relative terms. A transition away from coal would thus require (i) that the environmental objectives reach higher priority, or, (ii) that alternatives to coal satisfy the current objectives. The relevance of environmental objectives may, for example, increase via strengthened environmental NGOs or international influence. Interestingly, the importance of NGOs seems to increase in some countries, and environmental objectives play an increasingly important role, especially in China. However, economic growth and low energy prices are likely to remain major objectives in emerging economies [86]. Highlighting environmental and health co-benefits alone is unlikely to be sufficient. Working on narratives that emphasize the economic opportunities of REs in lowering electricity prices and working on strategies that reduce investment risks for such technologies could be coupled with outlining the economic disadvantages of coal, such as potentially stranded assets and substantial health costs.

Third, regarding the relevance of our results for future policies to phase-out coal, additional survey questions suggest that the expected operating coal capacity in 2040 may roughly equal that of today: the last commissioned coal-fired power plant is expected by 2023 in Turkey and 2049 in South Africa (see Fig. 1).[12] Although these responses are incomplete, quite dispersed and thus do not provide robust evidence, they suggest a severe conflict between the expected coal deployment and the Paris Agreement, which requires global coal capacities to be phased out by 2050 [5]. During the Conference of the Parties (COP) 26 in Glasgow in 2021, one year after our survey period, more than 40 countries, including Indonesia and Vietnam, signed the Global Coal to Clean Power Transition Statement. Signatories pledge to abstain from building new coal-fired power plants, and to eventually phase-out coal under certain conditions. The Glasgow Climate Pact, the first treaty of a COP that specifically considers coal, at least envisages a phase-down of unabated coal. It remains to be seen whether these pledges imply that policymakers will successfully manage to overcome the previously discussed driving forces for coal. Previous coal-dependent countries, which have successfully initiated a coal phase-out, typically applied a mix of policies that fostered a coal decline via regulatory instruments [32]. They simultaneously supported innovation and phase-in of REs via renewable support schemes. However, our sample mostly comprises emerging economies that are subject to additional constraints and are currently developing their energy systems. International coordination [87] and finance may play a decisive role for both reducing coal and supporting REs, while technical support as well as support for workers that would lose their jobs in the coal sector may also be part of the solution.

Finally, we contribute to the literature by scientifically assessing how actors, objectives, contextual factors, and pro-coal tactics and arguments relate to each other and across countries based on quantitatively comparable evidence. We retrieve our insights from homogeneous, novel, and nuanced cross-country survey data, and thus complement previous comparative papers, such as systematic reviews, or studies based on macro-indicators. Our findings allow assessing which previous findings from country studies are generally valid, and which are idiosyncratic to specific contexts.

Several limitations apply to our study, in addition to general caveats of expert surveys.[13] First, to keep a narrow focus, we exclusively elicit corporate political strategies but disregard the equally interesting role of vested interests of policy makers. This points to another

[12] The elicited energy experts were asked (i) about their expected operating coal capacity in the year 2040, and, (ii) for which year they expect the last commissioned coal-fired power plant.

[13] See Morgan [88] for a critical discussion of expert surveys in general, and Sovacool et al. [89] for a brief discussion of surveys studies in energy social science.

related caveat, namely the distinction between state-owned enterprises and policy makers. Although state-owned enterprises have no formal legislative power, they may have quasi-regulatory functions.

Second, there are limitations to our comparative survey approach. To reduce the cognitive burden on our respondents, we kept definitions within the survey to a necessary minimum. We conducted pre-tests to ensure precise questions and unambiguously defined concepts, but cannot fully ensure completely accurate, and thus valid, responses. To enable comparability, we disregard potentially relevant country-specific actors and institutions.[14] Furthermore, we aggregate individual actors into groups and thus disregard potential within-group differences as well as the pluralism of incumbent actors [90].

Third, researchers and NGO representatives, jointly comprising the largest share of responses, constitute only a subset of relevant energy expert opinions, which risks creating a sampling error. Yet, we especially expect researchers and NGO experts to have a broad and systemic perspective on coal politics. While NGO experts may be generally more normatively motivated than researchers, we do not see how this should fundamentally affect their perceived relevance of the elicited political economy factors. Other practitioners, or policymakers, could, theoretically, contribute at least equally interesting insights. However, we suspect that actors from these groups may have an incentive to provide motivated responses, for example by downplaying the influence of economic actors. Moreover, their perspectives may be more narrow on their specific domains. Non-researcher experts are thus only included if they were directly recommended by researchers. We think that our approach to identify experts builds a reasonable trade-off between selecting knowledgeable experts and a broad coverage.

Finally, our findings and their interpretation may be affected by our method of calculating the sample mean, outlier responses affecting the country means and the structure of missing entries. We provide detailed results of our robustness checks in the SI. Overall, we find that the alternative options for calculating the sample mean lead to largely similar outcomes and that the mean responses by country are only slightly affected by outliers. Analyzing missing entries shows distinct patterns in selected questions and response options. In particular, many missing entries with country-specific patterns occur for the questions on public economic actors, private economic actors and tactics. These survey outcomes should be considered with particular caution. We also tested whether excluding responses (i) by recommended energy policy experts, and (ii) by non-researchers lead to systematically different responses. We find that the overall results remain unchanged (see SI).

7. Conclusion

Our comparative study based on a cross-country survey of 123 energy experts assesses expert opinions about political economy factors stabilizing coal from the combined perspective of the AOC and CPS frameworks [19,24]. The sample covers eight major coal countries that will decisively influence to which extent the goals described in the Paris Agreement can be achieved.

We find that political actors, and in particular the ministry for energy, the head of state and the ruling party, are the most relevant political actors. Economic actors, and especially utilities and mining companies, are also highly important, although responses deviate depending on the economic system. The importance of economic actors is underlined by the most relevant contextual factors, namely the power sector influence and the power market structure, while lobbying is the most relevant tactic of pro-coal companies. Other societal actors, and also environmental actors, objectives, and contextual factors are consistently less important. Finally, we find that economic growth has a pivotal role; this major societal objective and contextual factor is both a goal and driver of coal deployment. Our findings can help to inform the design of politically feasible strategies to phase-out coal in different country contexts.

[14] For example, India's Ministry of Coal is obviously a highly relevant actor, that, however, has no analogue counterparts in other countries.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.erss.2022.102590.

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Chapter 4

The political economy of coal in India - Evidence from expert interviews

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The political economy of coal in India – Evidence from expert interviews

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ABSTRACT

Indian coal power capacity has doubled in the last ten years, and its coal pipeline is the second largest on the globe. This paper analyzes the political economy determinants of India's reliance on coal in the power sector. We base our analysis on a novel theoretical framework to assess how actors having different objectives shape coal investment decisions in India. Our results are based on the analysis of 28 semi-structured expert interviews conducted in Delhi. We find that India's substantial expansion of coal power can be explained by the following factors. First, the power sector was liberalized to ensure sufficient supply. This resulted in large industry conglomerates investing in coal and securing long-term profits as renewable energy support was ineffective. Second, the planned public investments in new coal capacity are motivated by securing the long term availability of electricity. Third, the reliance on coal in Eastern India for jobs, and the presence of local vested interests, are major barriers to a transformation away from coal. Fourth, pollution regulations that would limit coal use are ineffective because of the strong political influence of coal-proponents.

Introduction

To remain well below 2 °C, as agreed in the Paris Agreement, carbon-emitting coal-fired power generation needs to be phased-out by 2050 (IPCC, 2019; Luderer et al., 2018). However, instead of being gradually decreased, the global coal capacity is planned to increase by another 25% in the upcoming years (Shearer et al., 2020). If these additional plants are built, they could become stranded before the end of their economic lifetime. Given that two thirds of India's coal-fired power plants were built in the last 10 years and that India has the second largest coal pipeline, more than half of these plants risk being stranded after 2030 if India were to pursue policies in line with the Paris Agreement (Malik et al., 2020).

Why does India rely on coal in the power sector? Economic and technological reasons alone cannot explain the large pipeline and the existing plants. The price of renewable energy (RE)[1] in India has reduced dramatically (Creutzig et al., 2017), and recent RE projects are cheaper than many existing coal power plants (Somanathan & Chakravarty, 2019). In addition, the health effects caused by local air pollution arising from power generation based on coal are substantial; coal combustion was responsible for almost 170,000 deaths in 2015 in India (GBD MAPS, 2018). In previous energy transitions, political factors were often as important as economic and technological factors in explaining power sector development (Biber et al., 2017; Geels et al., 2017). In this context, we analyze the political economy of the Indian power sector with a specific focus on coal.

Our study contributes to the existing literature on the political economy of energy in India. A large body of literature focuses on the uptake of REs (Isoaho, Goritz, & Schulz, 2017; Krishna, Sagar, & Spratt, 2015; Ramamurthi, 2016; S. Shidore, Busby, 2019b; Tagotra, 2017; Tongia, 2007). International pressure has been found to be an important enabler for RE investment (S. Shidore, Busby, 2019b). The largest barrier to REs is financial distress of the electricity distribution sector (S. Shidore, Busby, 2019b; Tongia, 2007), caused by the use of low electricity tariffs as a tool for political patronage (Mahadevan, 2019; Min & Golden, 2014). Electoral opportunism and strong vested interests in the sector are major difficulties that hinder power sector reforms removing these barriers (Cheng et al., 2020; Dubash, Kale, & Bharvirkar, 2018). Only a few studies have investigated the political drivers of coal in the power sector. Tongia and Gross (2019) find that coal mining is central to India's political economy because it is an essential revenue source for the central government, the state governments, and state-owned enterprises, such as Indian Railways, the largest employer in the country (Kamboj & Tongia, 2018). Worrall, Whitley, Garg, Krishnaswamy and Beaton (2018) identified all the government policies incentivizing the use of coal in the power sector. We contribute to this literature by providing, to our knowledge, the first comprehensive and theory-guided analysis which focuses explicitly on the determinants of the past and planned focus on coal capacity in the power sector. By doing so, we

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[1] With RE we imply wind and solar power, unless specified differently.

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also contribute to a growing literature focusing on the political economy of coal in other countries (e.g., Brauers & Oei, 2020; Dorband et al., 2020).

We conducted semi-structured interviews with 28 energy experts and policymakers in Delhi. We systematically coded the interviews to classify actors, objectives, and contextual factors that influence coal-related policies. We cluster our results around three overarching objectives: providing sufficient and cheap electricity supply, promoting domestic industries and personal interests, and mitigating air pollution and climate change. The analysis is conceptually based on a novel political economy framework (Jakob et al., 2020). In general, the framework assumes that political and societal actors try to influence energy related policies. All actors are guided by multiple objectives, while a variety of contextual factors determine the relevance of objectives and the influence of actors.

Our analysis shows that India's reliance on coal is driven by direct government intervention in the power sector to secure long-term electricity supply. Public sector undertakings (PSUs)[2] along the coal supply chain are used to create regional employment and prosperity and strong vested interests also exist. Environmental concerns are more important now than in the past, but not significant enough to overcome powerful incumbents in polluting sectors such as coal generation.

The remainder of the paper is structured as follows. Section 2 describes the historical and projected development of the Indian power sector. Section 3 describes our research design, while Section 4 extensively describes our findings. We discuss broader implications for an Indian energy transition and conclude in Section 5.

India's power sector

Structure of the power sector

The Indian power sector is governed by several ministries, associated PSUs, and government agencies. Fig. 1 shows the organization of the Indian power sector and how it relates to coal mining, transport, and manufacturing of power plants.

The central government approves most energy policies. Within the central government, the Prime Minister Office (PMO) has a special role, as it decides the most important policy issues. Subordinate to the PMO are multiple specific ministries, which regulate different segments of the sector, but require the PMO's approval for changes in regulations.

The Ministry of Coal is responsible for regulating the production, supply, distribution, and pricing of coal, and implements its regulations directly through the quasi-monopolist PSU Coal India Limited (CIL). Coal in India is transported via railways that are managed by the Ministry of Railways and operated by the PSU Indian Railways. Bharat Heavy Electricals Limited (BHEL), an engineering and manufacturing PSU of the Ministry of Heavy Industries, manufactures products for the power sector such as turbines and boilers for thermal power plants and transmission lines. The Ministry of Power is in charge of the planning, policy formulation, and enactment of legislation concerning thermal and hydropower generation, transmission, and distribution. Furthermore, through the PSU National Thermal Power Corporation Limited (NTPCL), it controls 16% of the power capacity of the country. The Ministry of New and Renewable Energies regulates wind, small hydro, biogas, and solar power. Since 2014, it has been headed by the same minister as the Ministry of Power. Finally, the Ministry of Environment, Forestry, and Climate Change (MoEFCC) enacts environmental regulations and approves environmental clearances for power projects and new mines. However, these regulations are often not binding or weakly enforced by other ministries and PSUs (Stuligross, 1999).

Governmental agencies support the ministries in managing the power sector. The Central Electricity Authority (CEA) is a statutory organization that advises the Ministry of Power on development plans for the electricity system. Every five years, the CEA releases the National Electricity Plan, which outlines the development of the power sector in the medium-term. The Central Electricity Regulatory Commission (CERC), another key regulator, defines the guidelines for the Power Purchase Agreements (PPAs) between power generation companies and distribution companies (DISCOMs). NITI Aayog is a policy think tank that was established by Prime Minister Modi in 2014 to advise the Prime Minister Office and facilitate cross-ministerial cooperation. Since then, it has been heavily involved in power sector management, for example by drafting the National Energy Policy in 2019, which includes scenarios of long-term development pathways for the power sector.

Apart from the central government, state governments also influence the power sector. The central government is required to consult with state governments on policies concerning the power sector because electricity is listed as a concurrent subject[3] in the constitution. The state governments and the central government are jointly responsible for fostering electrification. State governments are also financially involved in electricity generation, as they are often major shareholders of local power plants. Besides power generation, they also have the greatest influence on electricity distribution as they own most DISCOMs. These buy electricity from generation companies and sell it to consumers. Usually, each local DISCOM signs long-term PPAs with electricity generators for 20–25 years, specifying the amount and price of electricity to be procured. These contracts generally guarantee a contribution towards fixed costs of power plants, even if electricity is not purchased. PPAs also regulate those who bears the financial burden of changes in costs, e.g., changes in global coal prices.

The judicial branch of the government also influences the development of the power sector. The Supreme Court takes up appeals primarily against verdicts of lower ranked judicial institutions. Among these, the National Green Tribunal (NGT) is of particular relevance in the power sector, as it handles environmental issues.

Historical development of the power sector

In recent decades, India's power sector has been through a number of reforms that have led to the liberalization and rapid expansion of total installed capacity. Fig. 2 shows a timeline of the additions to annual capacity by power source since 1965 and the most important events and policies in the power sector.

Between India's independence in 1947 and the year 2003, the power sector was centrally managed via a system of five-year plans. These plans were developed by a planning commission,[4] which regularly set new targets for power capacity. However, until the early 2000s, the grid expanded faster than the installed capacity and the excess electricity demand led to frequent power shortages. This demand-supply mismatch was driven by delays of centrally planned generation projects, while regional governments expanded the grid access despite the insufficient capacity. It was believed that liberalizing the power sector would solve these supply shortages. However, the first attempt to liberalize the power sector with the Independent Power Producers policy in 1992 failed to provide the necessary guarantees to attract private investment (Dubash, Kale, & Bharvirkar, 2018; Sreenivas et al., 2018).[5]

[2] Public sector undertakings is the official classification of state-owned enterprises in India.

[3] In the Indian constitution, the legislative section is divided into three lists: Union List, State List and Concurrent List. Items in the Concurrent List are required to be considered by both the union and state government.

[4] This planning commission was dissolved in 2015 and substituted by NITI Aayog.

[5] The only purchasers of electricity at the time were State Electricity Boards (SEBs) and their financial situation was disastrous. Political interference in tariff setting lead to SEBs selling electricity at non-cost recovery prices (Min & Golden, 2014). Widespread theft and transmission losses exacerbated the financial burden of SEBs. This financial situation made them an unreliable payer and thus increased the risk for private investors entering contractual obligations. Therefore, private investors demanded counter guarantees from the central government to isolate them from the risk of not being paid (D'Sa et al., 1999). For a detailed analysis of the reform process see, e.g., Dubash et al. (2018); Lal (2006); Singh (2010).

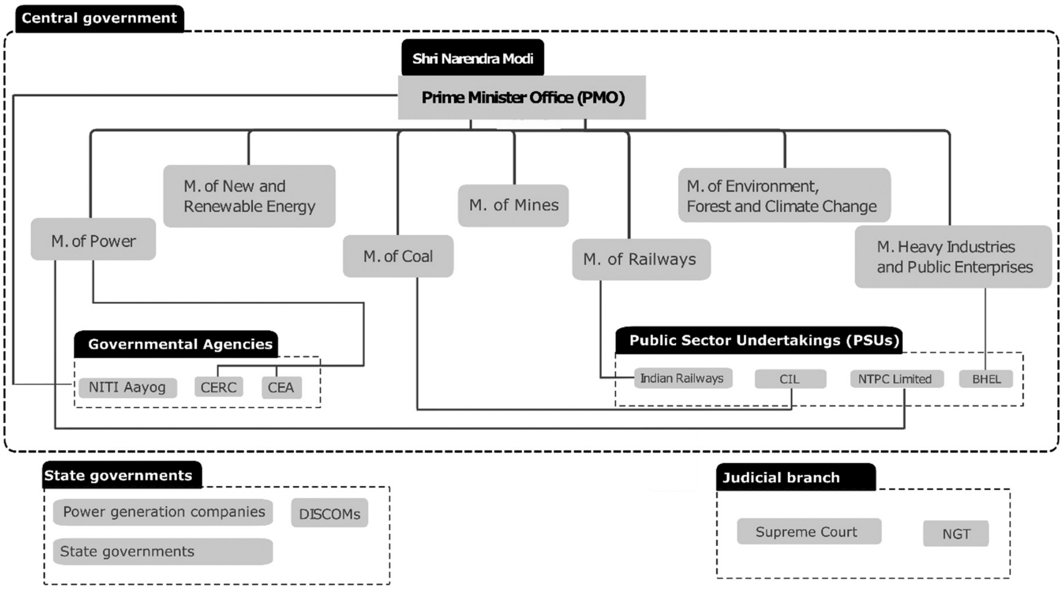

Fig. 1. *Power sector governance structure.* Acronyms: CERC = Central Electricity Regulatory Commission, CEA = Central Electricity Authority, CIL = Coal India Limited, NTPCL = National Thermal Power Corporation, BHEL = Bharat Heavy Electricals Limited, DISCOMs = Distribution Companies, NGT = National Green Tribual.

The Electricity Act in 2003 more successfully liberalized the Indian power sector. This cornerstone legislation mandated the unbundling of distribution and generation, the creation of a regulatory agency that overlooked the determination of tariffs (i.e., CERC), introduced competitive bidding for power projects, and effectively liberalized the import of coal by private actors. Since then, prices for PPAs have been determined via reverse auctions (Sreenivas et al., 2018). However, NTPCL was exempted from this provision until 2011 and was allowed to bilaterally negotiate tariffs with DISCOMs. The principles of the Electricity Act were implemented by the National Electricity Policy of 2005, and the National Tariff Policy of 2006. The liberalization led to a sharp increase in mostly private investments in power capacity additions (see Fig. 2). Between 2003 and 2011, 40 GW of privately financed coal capacity was commissioned (Sreenivas et al., 2018) and in 2019, 46% of the total installed power capacity was privately owned (CEA, 2020). This market share is highly concentrated within a few companies: Adani, Tata, Reliance, and Jindal Group account for almost 70% of the coal-fired power plants that were contracted between 2006 and 2011 (Gadag, Chitnis, & Dixit, 2011). Some DISCOMs, especially in large cities, are also privately owned by Tata Power and Adani Transmission, both operating in Mumbai and Delhi.

Coal thereby maintained and further strengthened its role as the largest source of electricity in India. In 2010, coal-fired power capacity accounted for 65% of the installed capacity mix, hydropower 22%, natural gas 8%. Nuclear power played only a relatively marginal role (3%) (WEPP, 2017). In 2020, there is 228 GW of operating coal-fired power capacity (Shearer et al., 2020), generating 74% of total electricity. Coal-fired power plants are installed in almost every Indian state (see Fig. 3). However, in Eastern India, there is an especially high concentration of installed coal capacity relative to population and regional GDP. The Eastern states of Jharkhand, Odisha, Chhattisgarh, West Bengal together host 80% of the total coal reserves in India (MOSPI, 2019) and are often

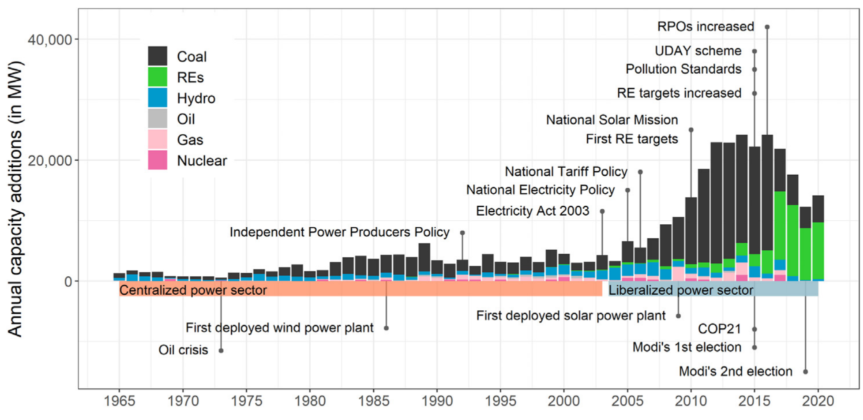

Fig. 2. *Annual capacity additions by source (including a timeline of relevant events).* Sources: Own elaboration based on WEPP (2017) until 2016 and CEA (2020) until 2020. Acronym: RPOs = Renewable purchase obligations, UDAY = Ujjwal DISCOM Assurance Yojana.

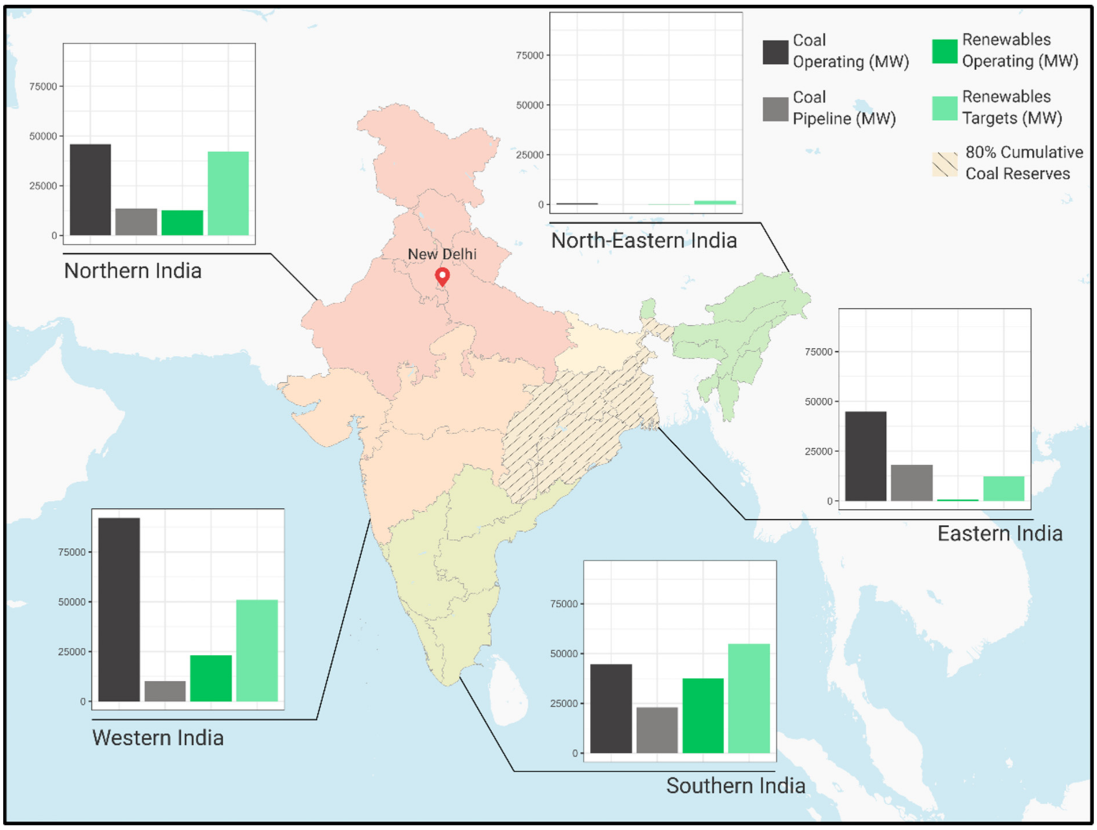

Fig. 3. *Geographical distribution of coal and RE capacity in MW (existing and planned)*. Sources: Own elaboration. Total installed capacity by region of REs (wind and solar) as of September 2020 is taken from MNRE (MNRE, 2020). Tentative state-wise breakdown of RE targets for 2022 (which differ from the actual pipeline) are taken from MNRE (MNRE, 2015). The coal pipeline refers to plants that are announced, permitted, or already under construction. Both pipeline and operating coal capacity are taken from Shearer et al. (Shearer et al., 2020). The dashed pattern indicates the states, which host 80% of India's known coal reserves. The geographical clustering follows CEA definitions and is in line with the electricity grid clusters.

referred to as the Indian "Coal Belt". Known coal reserves in India amount to a total of 319.04 billion tons of mostly low calorific coal, potentially allowing continuous extraction at current rates for another 500 years (own calculation). However, India also depends on high calorific imported cooking coal. Despite abundant natural resources, the regions in Eastern India are among the poorest of the country in terms of per capita income.

Since 2010, RE capacity has substantially increased, but remains low compared to the total installed coal capacity. The deployment of wind power started in 1995, while the first solar plant was built in 2009. In 2010, Prime Minister Manmohan Singh inaugurated the National Solar Mission, an initiative to promote the use of solar power. This Mission set the first target of 20 GW of REs (including small hydro and biomass) by 2022, thereby laying the ground for their further development. This target has since been increased by the current Prime Minister Modi; after his first election in 2015, just before COP21, he announced an increase of the RE target to 175 GW by 2022.[6] In the same year, the Ministry for Environment, Forestry, and Climate Change released more ambitious pollution regulations for thermal power plants, and Renewable Purchase Obligations (RPOs), increased from 3% in 2006 to 8%. Finally, the PMO adopted the UDAY scheme, a program to improve the financial situation of DISCOMs by limiting the level of debt they could contract. Jointly, these policies gave a boost to the RE deployment, especially in the solar sector. In 2020, wind and solar capacity make up respectively 10% (38 GW) and 9.5% (36 GW) of the total installed capacity (CEA, 2020).[7]

Since 2016, the power sector has officially been in a state of oversupply, caused by the sharp increase of annual capacity additions after 2010. In 2019, coal-fired power plants operated at plant load factors (PLFs) of an average of 56% (CEA, 2020). The overcapacity led to plummeting new coal-based capacity additions, while DISCOMs refrained from providing new long-term PPAs. The Standing Committee on Energy (Standing Committee on Energy, 2018), a committee consisting of Members of Parliament, estimates that there are 40 GW of recently deployed coal-fired power plants that have become non-performing assets.

Despite the oversupply, the quality of electricity for Indian households remains low, with frequent load shedding, brown-outs, and electricity being available only at limited times in some villages (Pelz & Urpelainen, 2020). This is explained by the large budget deficits of DISCOMs, which lack the financial capacity to buy the necessary power to serve all consumers. The dire financial situation of DISCOMs results from a long history of politically set low electricity tariffs, allowing theft and unmetered consumption (Dubash, Kale, & Bharvirkar, 2018). Hence, some DISCOMs are reluctant to sell electricity

[6] Distributed as follows across technologies: 100 GW from solar, 60 GW from wind, 10 GW from bio-power and 5 GW from small hydro-power.

[7] The geographical distribution of RE capacity is not homogeneous (Figure 3). The majority is concentrated in Western and Southern India, which both have favorable wind and solar conditions. REs are envisaged to increase from roughly 10% in 2020 to 35% of total installed capacity in 2022. Currently planned RE investments are also mostly concentrated in Southern, Western and Northern India (Figure 3).

or provide a grid connection to consumers eligible for subsidized tariffs; they prefer industrial consumers, who pay higher tariffs to compensate partially for the lower tariffs of domestic and agricultural consumers.

Coal is projected to remain the largest source of electricity until 2050, despite a constantly increasing share of REs. The National Electricity Plan of 2018 estimates that the share of coal in power generation will decline from 72% of generation in 2019 to 48% in 2030 (CEA, 2018). However, the total coal-based electricity generation is expected to increase by roughly 60% from 805 GWh to 1300 GWh, as the National Electricity Plan assumes an average annual electricity demand growth of 4.5%.

Methodology

We base our analysis on a novel actor-centered political economy framework developed by Jakob et al. (2020) (see Fig. A.1 for a visualization). The framework is guided by the idea that the energy policies that are implemented, are those which best comply with the objectives of the most influential actors. In the framework, each actor has a specific set of objectives, which are represented, by different degrees, in the policy outcomes according to the actor's influence on policy formulation processes. Political actors have a direct influence on the policy formulation process (e.g. by writing or adopting legislation or regulations). Societal actors, in contrast, are not formally able to design policies but can influence political actors. Finally, contextual factors determine i) the importance of each objective for each actor ii) the influence of each societal actor on each political actor, and iii) the influence of each actor on the policy outcomes. Contextual factors comprise economic, environmental, and institutional aspects. This framework can easily and transparently be applied empirically and allows comparison across countries. For example, Dorband et al. (Dorband et al., 2020) applied the same framework to study the political economy of coal in Vietnam and (Ordonez et al., under review) for Indonesia.

Our main data sources are semi-structured expert interviews that we complement with extensive desk research. In total, two authors conducted 28 semi-structured expert interviews in October and November 2018. While conducting our interviews, we followed ethical principles in line with the Charter of Fundamental Rights of the European Union and the European Code of Conduct for Research Integrity. Before starting an interview, we explained the project, clarified that the responses would only be used for academic purposes and that the interviewee's identity would remain anonymous. We furthermore asked for the informed consent to record and later transcribe the interviews. Three cases restrained from allowing to record. The interviewers furthermore took structured notes during each interview, including their impression of the interviewee's statements. The structured notes were cross-checked between the two interviewers and discussed.

The sample selection followed a snowballing process (O'Reilly & Parker, 2013). First, we identified a set of relevant institutions that we categorized as political and societal actors in our theoretical framework. This identification was based on initial desk research of policy documents and scientific publications. For example, we assessed which institutions authored or commented on important policy documents, such as the National Electricity Plan, which was authored by CEA, and received comments from a long list of public and private institutions. We used the personal network of the authors and publicly available contacts of employees to find relevant experts[8] within these institutions and contacted them via email. Second, at the end of each interview, we asked for recommendations of further energy experts (Cohen & Arieli, 2011). We thereby iteratively extended our initial list of institutions. We repeated this procedure until the recommendations became repetitive and the new information obtained from each new interview became minimal, following the principle of thematic saturation (O'Reilly & Parker, 2013).

The final sample of 28 interviews includes at least one representative of most key actors in the Indian power sector.[9] We interviewed twelve experts from national societal actors (NSA) including research institutions, journalists, and non-governmental organizations, ten experts from national political actors (NPA) including ministries and regulatory agencies, three experts from public-owned enterprises (PEA), two experts from international societal actors (ISA), and one expert from a privately owned enterprise (PrEA). Table A. 1 contains a list of institutions covered. In the remainder of the paper, each interviewee is referenced by the type of actor plus a random number that has been assigned to each interview (e.g.: NSA1). This ensures that the referenced claims cannot be linked to a specific institution.

Our semi-structured interviews followed an interview guideline that consisted of three parts. The first part asks which are the most important power sector policies. The second part determines which actors are relevant for each decision-making process and why. The third part aims to identify relevant contextual factors and contains follow-up questions adapted to the specific expertise of each interviewee. We also used the third section to triangulate previously obtained information (the detailed interview guideline is available upon request).

We used the theoretical framework from Jakob et al. (2020) to guide our analysis. While coding our interview material, we identified whether a passage of the interview referenced to i) societal objectives ii) political objectives iii) societal actors iv) or political actors. For example, we classify as political actors all national and state level administrations, which officially adopt policies (e.g., all the ministries and the PMO) or actively participate in the policy formulation with the role of advising agencies (e.g. NITI Ayog, the CEA and CERC). Societal actors, on the other hand, comprise private and public companies like NTPC or Adani, but also NGOs and other citizen groups that can affect policies via influencing political actors.

Each passage has a second- and third-tier code to identify specific information about each coded actor and objective. For example, a societal actor could receive the second-tier code "Civil society" and the third-tier code "Farmers". These second and third-tier coding categories emerged from the data analysis resembling the open coding approach (Holton, 2007). Each passage could receive multiple codes. In total, 87 different coding categories emerged (47 actors, 40 objectives). The list of codes and their classification into societal and political actors (objectives) is shown in Table A. 2 in the Appendix. After coding all passages, we qualitatively assessed the influence of each political actor on the policy formulation process, the role of each societal actor on each political actor, and the role of objectives and contextual factors on the respective influence.

By analyzing the coded data through multiple iterations between the authors, we clustered our results under three main overarching objectives, namely i) provide sufficient and affordable electricity supply, ii) promote domestic industries and personal interests, and iii) mitigate air pollution and climate change (see Table A. 2 for the clustering). These objectives reflect the energy trilemma and are commonly identified in the energy transition literature as important (e.g., Jenkins (2014); Schmidt, Schmid, & Sewerin (2019)).

Each result section describes in detail how objectives and actors interact and how these can be used to explain India's reliance on coal in the power sector. Given the qualitative nature of the analysis, we do not explicitly refer to all coded actors and objectives in all instances, but try to discuss the most important relationships. Thereby we aim to fulfill the highest standard of objectivity and reproducibility by following a state of the art guideline for expert interview analysis (Bogner et al., 2009). Whenever possible, we have tried to triangulate claims across

[8] We define an expert following the established definition of Bogner et al. (2009), as an individual that has "technical, process and interpretative knowledge that refers to a specific field of action, by virtue of the fact that the expert acts in a relevant way (for example in a particular organizational field or the experts' own professional area)".

[9] We focued our analysis at the level of the Central government. For a detailed analysis at the State and district level analysis see e.g. Bhushan et al. (2020)

interviews. However, we acknowledge that the outcomes may contain subjective elements, as they necessarily partially depend on the authors' judgment.

Results

The next sections describe the main overarching objectives in the power sector, namely i) to provide sufficient and affordable electricity, ii) to promote domestic energy industries and personal interests, and iii) to mitigate pollution and climate change.

Provide sufficient and affordable electricity supply

Ensuring a sufficient and affordable electricity supply was frequently mentioned as a major objective in the power sector (ISA2, NSA3, NSA4, NSA5, NSA6, NSA9, NSA10, NPA2, NPA6, NPA8, NPA9). As a domestically abundant and cheap resource, the Indian government perceives coal as the most favorable option to ensure a reliable electricity supply. The government has thus created a policy environment in the power sector favoring coal that largely remains today and, after the power sector liberalization, has attracted profit-driven private investors. Incentives for REs remained ineffective until 2016, largely due to the bad and unresolved financial situation of the DISCOMs. While private coal investments plummeted in the late 2010s, public coal investments remained to ensure uninterrupted availability of electricity in the future.

Sufficient supply

To satisfy the rapidly growing electricity demand and to ensure energy security, the Indian government has been incentivizing the use of coal since independence (NSA5, NSA11). Until the early 1990s, India's economic policy focused on centrally managed rapid industrialization, which required substantial investments in power infrastructure. During this period, the oil crisis of 1973 exacerbated the need for domestic energy sources (NSA11), while modern renewable energies were not yet an established alternative. The lack of alternatives made large scale coal-fired power plants, and to a lesser extent,[10] hydropower plants an obligated choice for the government (NSA2).

To implement these projects, the central government used PSUs and finance from other publicly owned institutions, such as the Power Finance Corporation and the Rural Electrification Corporation (Worrall, Whitley, Garg, Krishnaswamy, & Beaton, 2018). The central government also implemented policies to incentivize private investments in the sector; most importantly, they encouraged long-term PPAs with a guaranteed payment of fixed costs (see Section 2), minimizing their investment risk (ISA2, NSA9, NPA10, NPA2). In addition, land and water resources have been allotted at concessional rates for thermal power projects, and return on equity remained unclaimed by the public financial institution (Worrall, Whitley, Garg, Krishnaswamy, & Beaton, 2018). Finally, income from power generation projects was subject to 100% tax breaks until April 2017 (Garg et al., 2017).

Private profits

Since liberalization, coal-fired power capacity has been the technology of choice for private investors, because the policy environment has been ensuring high profits and low interest rates (ISA2). Furthermore, many private conglomerates that entered the electricity generation market after liberalization were able to complement previous business activities along the coal supply chain. For example, Adani, India's largest port developer, became the largest private power producer in the country (2014). Tata and Reliance both owned DISCOMs in Mumbai and Delhi, which allowed them to negotiate convenient PPAs for their sister companies after liberalization (Sreenivas et al., 2018). Some of these private conglomerates also invested in domestic mining. Large power projects acquired mining rights on nearby reserves to privately mine the coal necessary for power production. Furthermore, Adani acquired mines in Indonesia and Australia to import coal to India.[11] The private investors in the coal sector increased efficiency, which was reflected by reduced power shortages and increased coal production. However, the involvement of private actors was not free of controversies: Between 2005 and 2009, more than 100 blocks (more than 20,000 MT of coal) were allotted to private actors at zero cost except for royalties (NPA2, PEA2, NSA10). This process of allotting the blocks was later canceled by the supreme court following a corruption scandal known as “Coalgate”. These investment incentives created carbon-intensive lock-ins and powerful incumbents. PPAs, ensuring the payment of fixed costs to thermal power plants, restricted the uptake of REs, despite their dramatic cost reduction (ISA2, NSA9, NPA2). Furthermore, the incumbents oppose policies that would remove subsidies or impose additional costs for coal-fired power generation (NSA3). For example, with the large fiscal reform of 2015, the tax burden for coal and coal-fired power was reduced, while the burden on solar and wind increased (NSA3). Some independent power producers lobbied to renegotiate even more favorable terms for their PPAs (The Wire, 2018). Lobbying is often successful due to the strong leverage of private conglomerates over the current government lead by the Bharatiya Janata Party (BJP) (ISA1, NSA3, NSA5, NSA6). Adani and Tata even have direct personal relationships with the prime minister and allegedly contributed to financing his campaign (ISA2, NSA4, NSA5).

However, the rapidly falling costs of REs have lead private energy incumbents to increase their investment in RE (NSA3). After the large increase in coal-based power capacity between 2005 and 2015, some existing coal-fired power projects struggle to remain profitable, and private developers have difficulties obtaining loans for new projects (NSA7). These factors have contributed to a significant decrease in private coal investment. The large conglomerates in the power sector are now competing for higher market shares in RE markets (Chawla et al., 2018). Despite this, the policy environment still favors coal and 11 GW of private coal capacity is in the pipeline and will possibly come online if electricity demand rises (PrEA1).

Low electricity prices

DISCOMs incur large losses because of the political will to maintain low electricity tariffs for consumers (Dubash, Kale, & Bharvirkar, 2018). Local politicians, in exchange for political support, often promise to reduce electricity prices and to provide reliable grid connections (Dubash, Kale, & Bharvirkar, 2018). They fulfill those promises by setting electricity tariffs at subsidized rates and by allowing theft and unmetered billing (Mahadevan, 2019; Min and Golden, 2014). These electricity tariffs set by politicians impose heavy financial losses on DISCOMs. Consequently, most DISCOMs do not recover their costs, and have to be regularly bailed out by the central government.

Our interviews confirm the finding from other studies (e.g., Tongia, 2007) that policy incentives for REs remain less effective because of the dire financial situation of DISCOMs (NSA11, NSA5, NSA3). In 2006, the National Tariff Policy introduced a feed-in tariff, which guaranteed a return on investment of 15% on RE projects and required DISCOMs to partly procure power from RE sources (i.e., RPOs). However, DISCOMs have been reluctant to increase their share of REs as they

[10] Large scale coal and hydro projects were both pursued by the government. However, coal has historically been more successful, as India built 60 GW of coal, but only 20 GW of hydropower between 1972 and 2000 (own calculation based on PLATTS 2017). Strong social resistance against large hydropower dams and the subsequent reluctance of international financial institutions, such as the World Bank, to support these projects explain the comparative advantage of coal (Khagram, 2004).

[11] Imported coal from Indonesia and Australia is competitive with domestic coal imported from the Eastern regions due to the high domestic freight transport tariffs (see Section 4.2). The entrance of imported coal in the Indian power market created a new source of competition for the Eastern mines and a new source of profits for private companies.

fear their financial problems will worsen because of the higher RE tariffs and because of the required grid investments for the RE integration (NSA3). To maintain low consumer prices, state governments often "*turned a blind eye*" towards the DISCOMs' lack of compliance (NSA3). The lack of enforcement of RPOs increased the risk of RE investments generating higher capital costs (NSA3), being the largest cost component of RE investments (Hirth & Steckel, 2016).

Since 2016, the financial problems of DISCOMs have been addressed more successfully by the government. The UDAY scheme improved their financial situation,[12] and the government has become more strict on the enforcement of RPOs (NSA3).

Long term security of supply

The Ministry of Power considers coal-fired power capacity necessary to ensure the security of supply and is skeptical about the potential of REs to satisfy the fast-growing energy demand (NPA4, NPA6, NPA8, NSA9). Coal-fired power capacity is regarded as a reliable technology for baseload capacity (NPA4, NPA6), and as the only technology able to meet the peak demand in the evening (10–11 pm) (CEA, 2019) (OI1). Given the large number of financially stressed assets in the power sector (see Section 2.2), private actors are reluctant to embark on new coal projects until PLFs begin to rise again (PrEA1). While the relative share of public investment in coal-fired power plants has declined since liberalization, the coal pipeline in 2020 is 83% publicly owned (own calculation based on Shearer et al. (2020)).

For the central government, NTPCL has been instrumental in ensuring energy security since liberalization. The government protected the dominant position of NTPCL during liberalization, despite the acceleration of private investment (NPA2).[13] For example, NTPCL was absolved by the Tariff Policy of 2006 from competitive bidding until 2011 (NPA2). In this period, NTPCL signed PPAs for more than 50 GW (Sreenivas et al., 2018). Public support for coal to ensure energy security via publicly-owned power plants emerges as the main driver of Indian coal investments in the future.

Promote domestic energy industries and personal interests

The energy sector has often been used to promote economic growth and job creation (NPA2, NPA3 NSA5), two primary objectives of the national government (ISA2, NSA3, NSA5, NSA11, NPA8). Indian PSUs satisfy those primary objectives and several more; CIL and Indian railways are large employers and contribute to regional development and re-distribution goals (Chandra, 2018). Similarly, BHEL and NTPCL are large coal incumbents that manufacture and operate coal-fired power plants and thereby play a strategic role in providing the country's energy security. Lastly, over time, vested interests along the whole coal supply chain have emerged.

Regional development and jobs

The relatively poor coal mining regions in the East strongly benefitted from, and still depend on, the coal industry (NSA10, NPA2, PEA2, NSA5). The central government used CIL to foster investment, create employment, and redistribute wealth in the coal mining regions (Chandra, 2018). In addition, CIL has built houses, public infrastructure, and provides healthcare services, contributing to the well-being of the entire region (Chandra, 2018). When large-scale coal mining began, formerly remote villages became business centers (PEA2). Coal mining also generated employment in further sectors, such as road construction, transport, hotels, domestic servants, and vegetable sellers (PEA2) (Pai and Carr-Wilson, 2018). Policy-makers build on continued coal production to improve their chances of re-election. For example, state-level parties put pressure on the central government to invest in large coal mining projects operated by CIL in their constituency (NSA5, PEA2, ISA1, NSA4). The Ministry of Coal has often been assigned to Eastern Indian politicians, who have been major political figures in their states (e.g., Shibu Soren and Mamata Banerjee). Coal interests exist at multiple governance levels: locally, providing jobs; directly, as small amounts of coal maintain livelihoods; and at the state and the central level, through the allocation of coal mining rights.

The relevance of coal for economic development was not confined to the Eastern states, since the fast growing Western regions were historically the main consumers of coal. Western regions put pressure on the central government to facilitate the diffusion of cheap coal over the national territory, which often created regional tensions. For example, the freight equalization policy, enacted between 1953 and 1993, ensured the same price of coal irrespectively of the location of the demand. As a consequence, businesses decided to set up industrial clusters near the coastal trade hubs in the West, far away from the Eastern coal mines (Toman, Chakravorty, & Gupta, 2003). Many mining intensive districts in the Eastern states thus remained extractive economies, dependent mostly on CIL to provide employment opportunities (Bhushan et al., 2020).

Job opportunities

Though historically important, labor unions in the coal sector currently have a limited influence on the BJP-lead government. Nationwide, coal strikes have often been threatened, and sometimes carried out. However, a shrinking formal labor force has reduced union's bargaining power, leading them to compromises and taking deals rather than being able to resist major policy changes in the sector. Informal employment, as well as contracted labor in the mining sector, have been constantly increasing (NPA8). Today, only 30% of mining employees are estimated to be formally employed (Bhushan et al., 2020). In addition, due to its profitability Coal India's has been able to offer many financial benefits to existing employees, and buy-in the major opponents to increasing privatization and subcontracting in the industry.

Yet, coal miners remain an important group of voters due to their large number and geographical concentration (NSA7). In the Ramgarh district of Jharkhand, for example, a household survey found that 59% of people in the sample derived their income from coal-related activities (Bhushan et al., 2020). Such high levels of dependence might as well be common in many coal districts across India. Thus, whether new jobs from the RE sector can replace coal related jobs remain an important concern of the government (NPA3, NSA3, PEA2).

Jobs in the RE sector do not, to date, geographically overlap with coal jobs. Coal jobs are concentrated in Eastern India, while solar and wind jobs are concentrated in the West and the South (see Fig. 3, Section 2.2). Given that Eastern Regions have thus far not benefitted from new RE related jobs, they persist in politically supporting coal (NSA10, NSA12, PEA2, NSA5). Developing adequate RE capacity to absorb coal related jobs might even be technologically and economically unfeasible due to the low suitability of the Eastern region from wind and solar (Pai et al., 2020).

In addition, the total number of jobs in India may decrease by transitioning to REs. While thermal power plants are manufactured domestically, 80% of solar cells are imported from China and Malaysia (NSA3, Energy, 2020). To protect and stimulate the domestic solar industry, in 2018 the Government of India introduced an import duty of 25% on foreign solar cells (Ministry of Finance, 2018). However, with its legal time span of only two years, the import duty is considered ineffective in fostering a domestic market and triggering large-scale investments (Dutt, Aggarwal, & Chawla, 2019). Besides, it has adverse climate impacts by reducing the competitiveness of solar power relative to coal (NSA3, Buckley and Garg, 2019).

[12] The Central Government changed course to increase its power over the state governments (NSA2, NPA6). It essentially reduced the ability of the state governments to use electricity subsidies before elections (see Section 2.2). Additionally, the Central Government proposes switching to a system of centrally managed direct transfers, rather than the electricity subsidies managed by the states.

[13] More details on the strategic role of other PSUs are presented in Section 4.2.

Revenues

Indian Railways heavily relies on revenues from coal transport to ensure profitability (NSA12) and to cross-subsidize passenger fares. It does this by overpricing freight transport, of which coal constitutes 44% (Kamboj and Tongia, 2018).

The increasing share of REs in the Western regions in the last decade, however, has put pressure on the Indian Railways business model. Coal power plants in Western regions, being far from coal-mines,[14] are beginning to be less competitive than the increasingly cheaper REs.[15] This has reduced coal demand, which has further decreased the coal revenues from freight transport. In response, Indian Railways set higher freight tariffs, making the remote coal-fired power plants even less competitive. This reinforcing feedback loop has led to a doubling of freight tariffs between 2012 and 2017 (NSA12).

Despite Indian Railways' partial dependency on coal revenues, we find no evidence that the company or the ministry of Railways exerts any pressure to delay an energy transition away from coal. In fact, Indian Railways seems to be actively seeking strategies to reduce its dependency on coal (NSA1, NPA4).

Coal is also an important source of revenue for the central government, which uses coal income to fund various regional development projects (IISD, n.d.). The “Clean Energy Cess”, a tax on coal, was introduced in 2010 at USD 0.80 per ton of coal and raised to USD 3.20 per ton in 2015 (Garg et al., 2017). Unlike carbon taxes that are designed to reduce the use of a pollutant, the “Clean Energy Cess” was primarily established to raise revenues, assuming a low elasticity of coal demand (NSA4).

Energy independence and personal interests

The electrical equipment and manufacturing company BHEL strategically contributes to India's energy independence and is also a large employer. Coal-related business activities contributed to more than 80% of BHEL's annual revenues in 2017–18 (BHEL, 2018). Decreased orders for coal-fired power plants would thus threaten BHEL's main source of revenues (ISA2). From a strategic perspective, there are concerns that shutting down the domestic turbine production could increase India's dependence on other countries and international companies, as turbines for potential coal-fired power plants in the future would then need to be imported. One interviewee thus speculated that pressure from BHEL, in combination with concerns over energy security, might explain why the National Electricity Plan suggests a stable flow of 3–5 GW of new annual coal capacity (ISA2). In addition, BHEL provided legal and technical support to facilitate the approval of the environmental clearances for several proposed coal-fired power plants that ordered BHEL turbines.[16]

Lastly, the presence of large public monopolies along the coal supply chain (i.e. CIL) has created multiple opportunities to extract rents. Local and national politicians have participated in businesses benefitting from coal, e.g. machinery suppliers, transport, or ash treatment (NPA2, PrEA1).

Mitigate air pollution and climate change

Most of the interviewees mentioned that the mitigation of climate change and local air pollution are also important objectives (ISA2, NSA3, NSA4, NSA5, NSA6, NSA9, NPA8, NPA10), especially since the COP21 in 2015. However, some explicitly emphasized that they are less relevant than the objectives previously described (see Sections 4.1 and 4.2) (NSA3, NSA11, NPA3). Key objectives were to foster the government's domestic and international reputation, which led to the approval of ambitious RE targets and anti-pollution regulations (see Section 2). However, the enforcement of environmental regulations remains limited, as actors profiting from coal have substantial influence over policymakers (see also Section 4.1).

International and domestic reputation

Higher RE targets and more ambitious pollution standards are two critical policies that have been promoted by Modi's government. The RE targets are in line with India's NDCs, which envisage a 40% share of REs in the installed capacity by 2030 and thus a substantial increase from the 24% in 2020 (CEA, 2020).[17] Enforcing the pollution standards would potentially further reduce the price-gap between renewables and coal[18] and may lead to the retirement of 6 GW of old power plants, which lack the physical space to be retrofitted (NPA9).

Environmental policies helped to promote Modi's international reputation and to establish better international relations (NSA3, NSA5, NSA11, NPA2, NPA8, NSA6, NSA12). The COP21 was Modi's first international event as prime minister and thus an occasion to establish diplomatic relationships (NSA3). By promising efforts towards climate change mitigation, the Indian government could ensure international support in other strategic topics, such as, for example, geopolitics (NSA3) (Shidore and Busby, 2019a).

Domestically, announcing ambitious targets for the expansion of RE energies helped Modi establish his image as a leader, innovator, and first mover, which later became instrumental in securing support for his re-election campaign (Shidore and Busby, 2019b). Setting ambitious RE targets was a low-cost political strategy (NSA3, NSA5), given that the electricity grid was capable of integrating the thus far low shares of fluctuating wind and solar electricity (NPA10). With the setting of the RE targets, private investments significantly increased. In addition, Modi wanted to distance himself from coal, which, at the time of his first election, was linked to several corruption scandals (ISA1, NSA11).

The reformed pollution regulations also addressed the requirement for reduced local pollution of the urban middle class (NSA12, NSA6). The rapidly increasing urbanization since 2010 exacerbated transport pollution in large cities, which regularly leads to “front page” newspaper articles and record-high pollution levels (NSA12). Urbanization and rising average incomes have created a vocal and politically organized urban middle class, which has become increasingly visible through additional registered environmental NGOs that influence the policy process. The main channels of influence of the NGOs are the National Green Tribunal and the Supreme Court. For example, Greenpeace criticized the lack of compliance with pollution standards by private power generation companies at the Supreme Court and the National Green Tribunal (Sethi, 2019; The Economic Times, 2017). While the Supreme Court had historically been reluctant to take strong action against the power sector, some interviewees claim that the increased relevance of pollution heightened the likelihood of more severe rulings against pollution technologies in the power sector (NSA12, NSA6).

Reduce regulations

Although the Indian government approved more stringent pollution regulations, they have only been weakly enforced due to successful lobbying of incumbents. For example, when the deadline for retrofitting set by the MoEFCC expired in December 2017, almost no coal-fired power plant had been retrofitted (Garg, Narayanaswamy, Ganesan, &

[14] Coal freight tariffs are calculated on a ton per km base. For power plants located far from a mine, coal transport costs can account for 50% of the total fuel cost (NSA5, NSA9, (Kamboj & Tongia, 2018)).

[15] These renewables plants (mostly solar PV) on the West coast (i.e. Gujarat) are particularly cheap because of the optimal location and policy incentives (mainly enforced RPOs and subsidized transmission charge) (NSA3, NPA10).

[16] For example, a 1080 MW project in Telangana was initially halted by the National Green Tribunal, but subsequently greenlighted by the Mistry of Environment after the intervention of BHEL (Mahajan, 2018; SourceWatch, 2019).

[17] The renewable shares include: Small Hydro Project, Biomass Gasifier, Biomass Power, Urban & Industrial Waste Power, Solar and Wind Energy.

[18] Retrofitting increases costs for coal power generation between 0.34 and 0.87 INR per kWh (V. Garg et al., 2019). With costs between 2.5 and 3 INR per kWh for recently deployed REs, pollution standards are a sizeable instrument to reduce the price-gap between coal and REs.

Viswanathan, 2019). Instead of fining non-compliant companies, the MoEFCC simply postponed the deadline to 2022 (Central Pollution Control Board, 2018). It was reported that the Association of Power Producers, an industry association for private power producers, having well-established contacts with the Ministry of Power and within the PMO (ISA1), successfully argued for the technical infeasibility of the deadline in 2017 and obtained a postponement. This case is a concrete example of a common process in India's policymaking: societal actors are formally eligible to provide comments and inputs to policies before their approval. Yet, whether these comments influence the policy design, depends in particular on the personal or institutional contacts with the decision-makers (ISA1, NPA5, NPA8, NPA9, PEA3). In addition, private companies often directly hire former government officials to exploit their network.[19]

Discussion and conclusion

Since India's independence, satisfying the demand for sufficient and affordable electricity has been a key objective for the government. Energy policies favoring coal were established, while publicly owned companies primarily commissioned large-scale coal-fired power plants. With the power sector liberalization in the early 2000s, private actors also heavily invested in coal projects, not least because incentives for renewables were ineffective. In 2020, planned coal-fired power plants are again almost exclusively publicly funded and satisfy the objectives of ensuring long-term security of supply and energy independence. Besides, there are additional drivers for the ongoing coal deployment; in addition to power generation, we find that publicly owned companies in India, especially CIL, create regional employment and economic opportunities, which lead to stark regional dependencies on coal. In addition, local and national politicians personally benefit from established and additional coal infrastructure. Despite this, the increasingly important environmental problems and pressure from the international community have recently resulted in more ambitious environmental policies, such as substantial renewable targets and more stringent pollution standards. While the renewable targets have successfully attracted RE investments, the enforcement of the pollution regulation has been delayed by private actors in the power sector.

Disincentivizing ongoing private and public coal faces various obstacles. Despite the overcapacity and the financial distress of operating coal-fired power plants, the coal pipeline still includes 54 GW from public, and 11 GW from private companies (as of July 2020 from Shearer et al. (2020)). Reducing the regulatory incentives favoring coal investments, and in particular, removing implicit and explicit coal subsidies, could effectively discourage additional private coal investments and potentially redirect financial flows towards renewables. However, redirecting public investment seems even more challenging, given that within the central government coal is considered the main source of power generation to ensure long-term reliable electricity supply.

Furthermore, we identify a number of additional barriers to declining public coal investment, namely i) a prevailing belief of parts of the Indian administration that coal is a superior technology compared to renewables, and that there are perceived techno-economic constraints of RE-based electricity systems, such as high storage costs and lacking grid stability, ii) a regional reliance on coal for development, jobs, and fiscal revenues, and finally, iii) vested interests of public actors.

To change beliefs and perceptions is extremely challenging. Even some interviewees in favor of an energy transition towards REs expressed doubt about the ability of REs to cover baseload electricity demand in India in the absence of economically viable storage options. Occasionally, interviewees mentioned that showcasing functioning electricity systems based on REs of industrialized countries could be pivotal in dispersing fundamental technological doubts. A larger penetration of global electricity systems with REs may thus contribute to such a mind shift, while international demonstrations among decision-makers could accelerate the process.

An inclusive regional transition that provides alternatives to coal in Eastern India could be an important condition for an eventual coal phase-out. Previous phase-outs in other countries show that abrupt and unmanaged energy transitions can create social distortions, while managed, but delayed and suboptimal, phase-outs, as in Germany, risk becoming extremely costly (Oei et al., 2020). Early and well-organized transitions may prevent regional coalitions of actors from slowing down or hindering a phase-out. A transition away from coal would require creating new economic, cultural, and educational opportunities for the regions involved. To ensure a just transition, the numerous, but only weakly represented informal workers in the mining sector, should receive particular consideration by transition policies. Thus far, discussions about energy policy in India have been concentrated at the national level. Involving the Eastern Indian “Coal Belt” states, in particular, would thus be a first and important step. Moreover, India could establish a discussion forum that develops ideas for future regional economic development and industrial diversification. This could involve representatives from different governance levels, but also non-governmental societal institutions (Chandra, 2019). In the absence of private investment, much of the Indian coal belt has been held up economically through public investment by various government programs, PSUs, and other mechanisms (Jaitley, 2017). Attracting new forms of private sector investment will be an important part of a just transition in India (Bhushan et al., 2020).

International financial institutions may provide further entry points for an Indian energy transition by, for example, increasing the share of loans which are conditional on sustainability criteria. International financial aid is often already targeted at RE development. Furthermore, international shareholders can pressure the Indian state-owned banks to avoid lending to carbon intensive projects (Ghosh, 2020). The COVID-19 crisis in 2020 might also increase the influence of international financial flows due to the lower revenues of the government and private companies. Yet, when loans are conditioned to sustainability criteria, monitoring and enforcing environmental regulations against the interests of powerful vested interests would remain an important challenge.

The COVID-19 crisis hit coal-fired power generation particularly hard. The fall in demand following the strict lockdown measures was almost entirely born by the coal power plants, with a decreased output of 29% in 2020 compared to 2019 (Parray, 2020). This exacerbated their already precarious financial situation and further reduced the demand for new coal-fired power plants. However, the crisis might also delay needed investments in the RE sector (Bridge to India, 2020). It remains to be seen which of the two effects will prevail. Despite these short-term developments, we expect that India's key objectives remain unchanged. It thus seems unlikely that the identified drivers for coal will soon disappear.

Declaration of competing interest

The authors declare no competing interests.

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[19] For example, the current director general of APP was a former government official involved in the power sector development (The Hindu Buisiness Line, 2011).

suggestions. This paper has not been submitted elsewhere in identical or similar form.

Appendix A. Supplementary information

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2021.02.003.

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Chapter 5

Conceptualizing Multi-Sector Transitions: the Discourse on Hydrogen in Germany

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Resubmitted to *Environmental Innovation and Societal Transitions*

Conceptualizing Multi-Sector Transitions: the Discourse on Hydrogen in Germany

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Abstract: With net-zero emissions goals, low-carbon transitions enter a new phase of development, leading to new challenges for policymaking and research. Multiple transitions unfold in parallel across multiple sectors, while actors engage in diverse and complex discourses. We explore some of these challenges by studying the German hydrogen discourse. Using 179 newspaper articles from 2016 to 2020, we find that a diverse set of actors, including many industry incumbents, support establishing a hydrogen economy by emphasizing hydrogen's relevance for the energy transition and economic opportunities, whereas skeptics outline its low energy efficiency and expected scarcity. We mobilize discourse network analysis to analyze three specific conflicts around the use, production, and import of hydrogen. We also develop an analytical framework that captures the interplay between multiple sectors, technologies, and actors engaging in discourses. Our conceptual framework helps to explain the rather unusual support of industry incumbents across sectors.

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1. Introduction

As more and more countries and businesses are making pledges to reduce their greenhouse gas emissions to net-zero until mid-century (Höhne et al., 2021), the transition toward low-carbon energy systems is entering a new phase of development. It is not sufficient any more to pursue incremental changes, or to focus on selected sectors, such as electricity or transport. Instead, societies need to cut, or compensate for all greenhouse gas emissions across all sectors.

This 'net-zero phase' of the energy transition imposes new challenges. One challenge is the simultaneous involvement of multiple socio-technical systems, or sectors, and various technologies within and across these multiple systems. Another challenge is the large number of actors from different backgrounds. Transitions research has begun to address some of these challenges, highlighting the increasing complexity if transitions comprise multiple sectors or multiple technologies (Papachristos et al., 2013; Rosenbloom, 2020; Andersen and Markard, 2020). Despite some progress, we still lack empirical studies and conceptual frameworks to analyze transitions which involve multiple systems (Rosenbloom, 2020).

We address this gap with a study on the emerging field of hydrogen, a research case that is at the heart of the latest phase of the net-zero energy transition (van Renssen, 2020). Hydrogen is currently pushed by policymakers as an alternative energy carrier for a broad range of applications, including difficult-to-decarbonize industries (DDI), such as steel or aviation (Davis et al., 2018). As of 2021, 17 countries have already adopted hydrogen strategies, and another 20 have strategies under development (IEA, 2021a). We select Germany as our research setting. Germany, as a leading industrialized country with many large incumbent firms in different industrial sectors, is an interesting case, and the German government actively promotes hydrogen as an essential part of its net-zero strategy.

We ask how actors view and talk about hydrogen, and whether and why they support or oppose to it. We also address how the views of incumbent actors may be affected by the sectoral context they are operating in. We approach these questions by analyzing the German hydrogen discourse in leading nationwide newspapers. Our analysis starts in 2016 and covers the years leading up to the end of 2020. The final dataset comprises 179 newspaper articles of five newspapers, quotes of 139 actors, and 30 storylines shaping the Germany hydrogen discourse. Discourse analysis can be a particularly insightful tool for innovations at an early stage of development (Rosenbloom et al., 2016), such as hydrogen. We also employ discourse network analysis (DNA) on a subset of storylines related to three emerging conflicts.

We find a widespread, partly even enthusiastic support for hydrogen among incumbent actors, while environmental NGOs and some think tanks adopt more skeptical positions. We also identify three specific lines of conflict, about in which sectors hydrogen should be used, which production methods are desirable, and on potential risks and benefits of hydrogen imports. Our findings are surprising when considering that incumbent actors have often resisted transformative change (Smink et al., 2015), and given that they come from a broad range of different sectors that are in different transition stages.

We also contribute by developing a simple conceptual framework to study the involvement of multiple systems (sectors), multiple technologies and multiple actors in discourses around emerging sustainability innovations. The framework considers the sectoral context, sector-specific technologies, and actor interests to understand how actors engage in the discourse. We apply our conceptual framework to the case of hydrogen, to better understand how the sectoral context of incumbent actors shapes their position towards hydrogen.

The paper proceeds as follows; Section 2 describes the theoretical background, Section 3 explains our approach and methodology. Section 4 presents the results. Section 5 discusses how the framework can help interpreting the findings. Section 6 concludes.

2. Theoretical background

Our study is rooted in the literature on sustainability transitions, which studies fundamental changes in socio-technical systems, and their repercussions for grand sustainability challenges, such as climate change (Markard et al., 2012; Köhler et al., 2019).[1] We understand the net-zero energy transition as a complex, long-term transformation process that involves multiple transitions in different sectors and places. In the electricity sector, the energy transition has already seen quite some progress, as fossil fuels are increasingly replaced by renewable

[1]In the following, we use the terms system and sector interchangeably.

energies (Mitchell, 2016). Low-carbon electricity has also become a viable energy carrier to decarbonize parts of the transport and building sectors (Markard, 2018).

With net-zero emission goals, the energy transition enters a new stage of development that goes beyond low-carbon electricity, and requires the development of alternative fuels, such as hydrogen. This new phase targets all sectors responsible for greenhouse gas emissions, including difficult-to-decarbonize industries (Davis et al., 2018; Bataille, 2020). One consequence is a significant increases of complexity with multiple transitions unfolding simultaneously. This novel setting is conceptually demanding as it is characterized by i) multiple systems in different transition stages, ii) interactions of multiple technologies, and iii) a broad range of different (incumbent) actors. Below, we briefly review these three issues. We also explain the merits of discourse analysis, and conclude with a conceptual framework that guides our reasoning, and facilitates the interpretation of the results.

2.1. Interaction of multiple systems

Originally, socio-technical transitions have been depicted in a rather straightforward way: innovations emerge in niches, improve and diffuse over time, until eventually, one innovation has matured sufficiently to replace established practices and technologies, thereby fundamentally transforming a socio-technical system (Geels, 2002; Markard et al., 2012). In this view, transitions are primarily confined to single systems, which limits the number of innovations, technologies and actors. Later, scholars have shown that innovations may not just interact with one, but with multiple systems at once (Geels and Schot, 2007; Raven, 2007; Konrad et al., 2008; Papachristos et al., 2013). One example is biogas technology: it connects agriculture on the input side with different energy sectors on the output side (Sutherland et al., 2015; Markard et al., 2016). Another example are multi-purpose, or general-purpose technologies, such as information and communication technology, that can be used for a broad range of applications (Dolata, 2009).

As transitions in single sectors progress and widen in scope, they may also affect different other sectors (Markard et al., 2020). The transition towards renewable energies in the electricity sector, for example, enables the electric mobility transition in transport (Zhang and Fujimori, 2020). These more complex interactions call for more research on multi-system dynamics in transition studies (Rosenbloom, 2020). Multi-system interactions also raise new questions, e.g. about how actors with different (sectoral) backgrounds and interests interact, how relationships between different systems change, or what trade-offs or conflicts unfold.

2.2. Interaction of multiple technologies

Next to multi-system dynamics, the net-zero energy transition is also characterized by an interaction of multiple technologies (Andersen and Markard, 2020).

Transitions research has already described various forms of technology interaction and the conditions, under which technologies compete or complement each other (Sandén and Hillman, 2011; Markard and Hoffmann, 2016). In the electricity sector, the transition towards renewables is already in full swing (Mitchell, 2016), and in transport and heating, technologies that rely on low-carbon electricity diffuse in many places (IEA, 2021a,b). Hydrogen is expected to emerge as an alternative low-carbon energy carrier, either in addition to electricity, or as the primary alternative to fossil fuels. As a consequence, hydrogen-based technologies may both complement, or compete with existing and alternative low-carbon technologies. What complicates the situation is that some hydrogen technologies and infrastructures may reach across sectors, which means that system and technology interaction overlap.

2.3. Incumbents in transitions

Actors such as firms, industry associations, think-tanks, NGOs or policymakers play a crucial role in transitions (Farla et al., 2012). While they pursue different, possibly conflicting interests and strategies, they deploy various kinds of resources, forge networks and engage in institutional or transition work (Binz et al., 2016; Löhr et al., 2022). Overall, they either seek to shape policies (Musiolik et al., 2012; Wesseling et al., 2014), or need to adapt to them (Löhr and Mattes, 2022).

Of particular interest are incumbent actors, especially when they are economically well equipped and exert political influence (Turnheim and Sovacool, 2020). Some incumbents control critical resources (e.g., access to specific customers or suppliers), which is why they can be central for developing, or slowing down, new technologies (Rothaermel, 2001; Berggren et al., 2015). Many studies have found incumbent actors fighting against major technological or institutional changes to protect their established businesses (Hess, 2014; Jacobsson and Lauber, 2006; Penna and Geels, 2012; Wesseling et al., 2014; Smink et al., 2015).

However, incumbent firms may also support or even drive transitions (Turnheim and Sovacool, 2020; Löhr, 2020). Transition scholars have shown pro-active strategies of incumbents in various sectors, including heavy vehicles (Berggren et al., 2015), electrical engineering, automotive (Bergek et al., 2013), or horticulture (Kishna et al., 2017).

2.4. Discourse analysis

When actors talk about innovations, they create narratives, or storylines, in which they (co-)create an image of the innovation and, through this, influence how it is perceived by others, e.g. whether it is regarded as legitimate or not (Rosenbloom et al., 2016; Markard et al., 2021). This kind of narrative work is crucial in early transition stages, when there is a lot of uncertainty around a novel technology (Binz et al., 2016), or in situations of 'regime destabilization' (Turnheim and Geels, 2012), when established practices are questioned (Rosenbloom, 2018). As actors come with diverging interests and from different sectoral backgrounds, we typically see a broad variety of arguments, including conflicting storylines (Geels and Verhees, 2011; Roberts and Geels, 2018; Isoaho and Markard, 2020).

In this paper, we mobilize argumentative discourse analysis, which rests on the assumption that language, and the exchange of arguments, play a key role in how problems and solutions are framed (Hajer and Versteeg, 2005; Brink and Metze, 2006; Hajer, 2006; Isoaho and Karhunmaa, 2019; Lowes et al., 2020). Discourse analysis can be particularly useful to study technologies in an early stage of development, in which uncertainties are high, and pathways (including specific configurations and applications) are still to be shaped (Rosenbloom et al., 2016). Storylines are a key concept in discourse analysis. A storyline is: "*a condensed statement summarizing complex narratives, used by people as 'short hand' in discussions*" (Hajer, 2006, p. 69).[2]

[2]Through storylines, actors express complex issues in simple ways. For example, a storyline such as "Hydrogen is needed for net-zero [energy systems]" entails several assumptions, including that hydrogen will

In our paper, we will use discourse analysis both qualitatively, and in a more formal way using DNA. This allows us to systematically trace who mobilizes which storylines, and which actors make similar arguments (Leifeld and Haunss, 2012; Leifeld, 2017). DNA has been applied to a broad range of issues including pension policy (Leifeld, 2013), nuclear and coal phase-out (Rinscheid, 2015), climate policy (Fisher et al., 2013; Kukkonen et al., 2018), energy transitions (Brugger and Henry, 2021), or genetically modified organisms (Tosun and Schaub, 2017). DNA is compatible with Hajer's conceptualization of discourse because it entails both a substantive dimension (arguments expressed through storylines), and a relational dimension in the form of actors sharing similar storylines (Leifeld, 2017).

2.5. Conceptual framework

This section seeks to integrate the different aspects we introduced above to explain how storylines form in a multi-sector, multi-technology setting. We build on Rosenbloom et al.'s (2016) analytical categories of actors, content and context and transfer them to a setting that is characterized by multiple systems and multiple technologies.

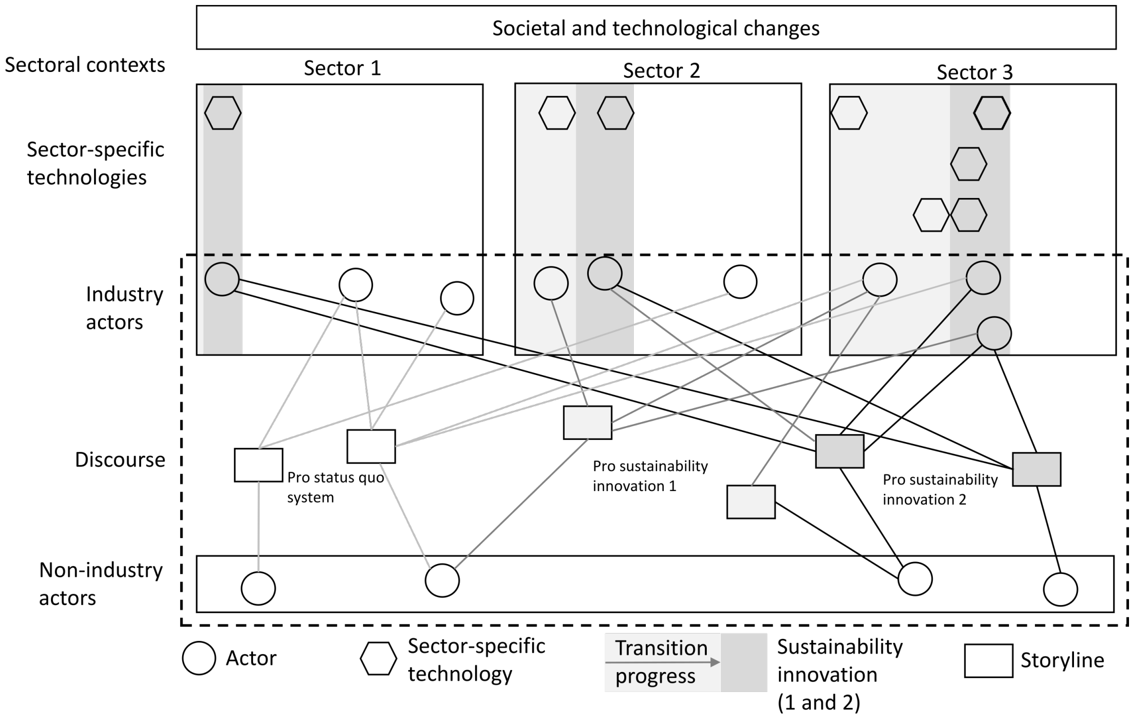
We distinguish between the 1) *sectoral context* (with multiple sectors in different transition stages), 2) multiple *sector-specific technologies* (with different socio-technical characteristics), and 3) strategic *actor interests*. Moreover, we assume that all sectors are affected by broader societal and overarching technological changes. The underlying idea is the following: how actors talk about an innovation depends on the availability and progress of other innovations, complementarities between the innovation and established technologies, infrastructures, business practices, and prior strategic commitments.

Figure 1 shows our generic framework, in which we distinguish i) three different sectors in different transition stages, ii) two sustainability innovations and one incumbent practice ("status quo"), iii) a variety of industry actors that we assign to the sectors as well as iv) other actors outside these sectors, and a v) discourse with a broad set of storylines surrounding both innovations and the incumbent practice. Sector 1 is at a very early sustainability transition stage and has only one sustainability innovation and sector-specific technology. In

become technologically and economically viable, available in sufficient quantities, and that alternative strategies to reach full decarbonization do not exist, or will not succeed.

the discourse, some industry actors already support the innovation, while others still promote the status quo system. In Sector 2, the innovations have already made some progress (the white space for incumbent practices getting smaller) with two equally advanced competing technologies. The actors are divided between all three options. Sector 3 has transitioned furthest and includes technologies at different stages of maturity. The actors have already abandoned the status quo, but are divided between the different innovations. In Section 5, we apply the framework to explain our findings, and discuss its broader implications for transitions research.

Figure 1: Conceptual framework



The conceptual framework describes the behavior in the discourse of actors from three different sectors at different stages of transitions. Each sector has an status quo socio-technical configuration (white area), that is challenged by one or two emerging and competing sustainability innovations (grey areas) and associated sector-specific technologies (hexagons). The position of industry actors (circles on top) in relation to these areas reflect the commitment of actors to the respective technologies. All actors, including non-industry actors from politics, or the civil society, and from economic sectors that are not affected by the sustainability innovation (circles at bottom), participate in the discourse by uttering storylines (rectangles) that favor one of the three options. Moreover, we assume that all sectors are affected by broader societal and technological changes.

3. Methodology

The following sections describe our research case Germany, the selection of newspaper articles, the development of the coding scheme, the resulting storylines, the overall sample, and finally, our analytical approach.

3.1. Hydrogen in Germany

We select Germany as our research case for studying the emerging discourse around hydrogen. Germany has Europe's largest economy, and the fourth largest nominal GDP on the globe (IMF, 2021). Germany's decisions about energy policies are important internationally, as they have already in the past spilled-over to other countries. For example, since the early 2000s, Germany's *Energiewende* demonstrated that a renewable energy transition is generally feasible, induced significant price reductions and efficiency improvements for renewables, and also promoted the expansion of renewables internationally (Quitzow et al., 2016). Understanding the German energy transition is also particularly challenging and complex due to the large variety of established industries with its diverse set of actors.

Especially the goal to decarbonize the entire economy made hydrogen come to the fore of the German government. In early 2019, the German chancellor Angela Merkel announced the new goal of achieving the net-zero emissions goal until mid-century, in contrast to the previous goal of decreasing carbon emissions by 80-95%. This paradigm shift implies decarbonizing the entire economy, including DDI sectors, such as the steel or chemical industry, or shipping and aviation (Davis et al., 2018; Bataille, 2020). Other reasons driving the recent uptake of hydrogen are generally changed economic conditions, as renewables had become increasingly cheaper, while increased prices of European Emission Allowances put additional pressure on energy intensive industries. Finally, hydrogen gained an international momentum triggered by Japan, which adopted a hydrogen strategy already in 2017.

Germany adopted a national hydrogen strategy in June 2020 as part of an economic stimulus package in response to the Covid-19 crisis (BMWi, 2020). The strategy covers national and international projects on the generation, transport, distribution and use of hydrogen. Germany envisages becoming a large-scale hydrogen importer, also from emerging economies. The strategy explicitly focuses on green hydrogen from renewable energies, while production methods based on fossil fuels were declared temporary solutions only.

3.2. Article selection and coding

We investigate the public discourse on hydrogen in Germany by analyzing articles of five leading newspapers comprising the *Süddeutsche Zeitung*, *Frankfurter Allgemeine Zeitung*, *Die Welt*, *Handelsblatt* and *taz*. This selection covers five out of six most printed national daily newspapers in Germany with a circulation above 750.000 per day (?), and addresses the entire political spectrum from left (*taz*) to mid-right (*Die Welt*). To identify relevant newspaper articles, we developed a search query that aims to cover a comprehensive selection of articles, while keeping the number of unrelated findings to a necessary minimum. The query includes articles with hydrogen mentioned at least once at the beginning, and four times in the main text.[3] To ensure that we include the start of the recent hydrogen discourse, we select articles starting with the year 2016 when the Paris Agreement was adopted. The search period ends with December 2020.[4]

The coding scheme was developed inductively and bottom-up in multiple iterations between the author team (Kuckartz, 2016). To familiarize with the topic, we complemented and triangulated our desk research via semi-structured interviews with nine hydrogen experts from NGOs, research institutes and a German ministry by mostly two or three authors in early 2021. To develop an initial coding scheme, each author independently read selected newspaper articles and proposed potential storylines. The selected articles were chosen to represent the entire range of the discourse, and thus include long articles from all five newspapers with different topics many direct quotes. The proposed storylines were subsequently discussed multiple times between the authors. In a next step, one author coded more than 10% of the sample and thereby refined the initial coding scheme. All study authors afterwards coded selected articles to compare their coding decisions, and to discuss and resolve

[3]The specific search parameters depend on the search options provided by the different databases used to search for the articles. These databases comprise Lexis (*Die Welt*, *Frankfurter Allgemeine Zeitung* and *TAZ*), WISO (*Handelsblatt*) and the SZ archive (*Süddeutsche Zeitung*). The coding was done using the qualitative data analysis software MAXQDA.

[4]We are aware that hydrogen has been at the center of attention already around the year 2000 and several times thereafter (Konrad et al., 2012; Budde and Konrad, 2019). Yet, the previously narrow focus on transport differs from the ongoing debate.

potential ambiguities. One author then coded all articles using the final coding scheme.[5] All coded passages that contribute to the results in Section 4.2 were checked by the entire author team to ensure the absence of coding errors. Identified double codes arising from identical text passages within different articles were removed.

3.3. The storylines

This analysis includes 30 storylines, which we grouped into six topics. Topics 1-3 are about the deployment of hydrogen in general, and 4-6 center around specific lines of conflict. Topics 1-3 address the role of hydrogen for climate change mitigation (1), economic considerations (2), and technical aspects (3) in a prospective renewable electricity system. In total, 9 storylines address these topics, while each respective topic is covered by three storylines. The remaining 21 storylines relate to three specific conflicts on the production method (4), hydrogen imports (5), and the use of hydrogen (6). Table 1 shows the short and long version of the storylines. The storylines referring to the specific lines of conflict are aggregated and assigned to either one of two opposing positions. Table 2 shows the short versions of the disaggregated storylines in the specific conflicts.

[5]The coding-tree in MAXQDA consists of short versions of each code. The long version, additional explanations, and coding examples are attached to coding memos.

Table 1: Storyline overview

Storyline short	Storyline long
1. Climate change mitigation (123)	
Important for energy transition	Hydrogen is an important part of the energy transition.
Required for complete decarbonization	Hydrogen is indispensable for achieving a complete decarbonization. Renewable electricity alone is insufficient.
Prioritize other climate mitigation options	The focus on hydrogen risks to distract from other mitigation options (e.g. renewable deployment, efficiency, sufficiency) that should be prioritized.
2. Economic considerations (114)	
Economic opportunities	Hydrogen creates economic opportunities (e.g. technology exports, jobs, new value chains) for Germany's economy or individual companies.
Eventually cheap option	Hydrogen will become a cheap energy carrier or at least profitable business case once cost reduction potentials are realized, or carbon costs increase further.
Generally scarce and expensive	Hydrogen will remain a scarce and expensive energy carrier, also in the future.
3. Technical aspects (71)	
Utilization of existing gas grid	Hydrogen allows utilizing the existing gas grid infrastructure.
Facilitates renewable integration	Hydrogen facilitates the integration of (excess) renewable energies and stabilizes the electricity system.
Low energy efficiency	Producing hydrogen is inefficient due to high energy losses.
4. Use (191)	
Wide use	Hydrogen should be used for private cars, domestic heating, blended into the natural gas grid, or generally applied widely.
Restricted use	Hydrogen should primarily be used for difficult-to-decarbonize industries, or not for private cars, heating or be blended into the natural gas grid.
5. Production method (171)	
Non-green necessary	Non-green hydrogen is required for a transition period, or relying on green hydrogen alone is not possible, expensive, or risky.
Exclusively green	Exclusively green hydrogen should be used, or only green is carbon free, or CCS is contested, or non-green hydrogen prolongs using fossil fuels.
6. Imports (85)	
Imports beneficial	Hydrogen imports will be comparatively cheap due to better wind and solar conditions, or exports will foster the economic development abroad.
Imports concerning	Hydrogen imports lead to new energy dependency from other countries, or other countries may face environmental problems (water scarcity) or human rights violations.

The table groups each storyline under one of six topics and shows a short (1^{st} column) and a long version (2^{nd} column). The number of coded passages for each topic are shown in brackets. Topics 4-6 aggregate several individual storylines; disaggregated short versions of these are shown in Table 2.

The analysis only includes a selection of coded storylines that we consider most insightful to understand the overall discourse, while it omits more detailed statements about sector or technology-specific aspects, such as the benefits of battery electric vehicles over fuel cell cars (or vice versa). Statements on single sectors are only included if they more generally address the conflict about where to use hydrogen. Further coded, but not included storylines, address potential consequences that result from deploying hydrogen, consensual statements related to the three specific lines of conflict, uncontested promoted uses of hydrogen, and particularly rare storylines.

3.4. The sample

The final sample comprises 179 newspaper articles with 614 coded passages by 139 actors. The initial search yielded 321 newspaper articles, of which almost 4000 passages were coded. To condense the analysis, and to focus on the most relevant aspects, we excluded several storylines (see previous section), and, removed false positive articles, articles without coded passages, duplicate codes by the same actor within single articles, and codes by journalists. Further information on the search query, and more details about the sample of newspapers are available in the Appendix A.1.

The actors covered by the analysis stem from a variety of different fields and industrial sectors. To facilitate the overview, we aggregate individual actors to groups, namely *Policymakers*, companies from the *Transport*, *Gas and heat*, *Industry* and *Electricity* sector. Two more groups comprise actors from *Research and think tanks*, and *NGOs*.[6] Within each industrial sector, the discourse is dominated by incumbents, while newcomers only play a minor role.

The distribution of storylines between actors is unequal, with a few actors activating significantly more storylines than others. Policymakers are most salient, specifically different ministers, but also members of the EU Commission and of political parties. Of industry actors, selected companies and industry associations from the automotive energy and gas sector are particularly visible (VW, BDI, RWE, Westenergy, Zukunfts Erdgas, FNB Gas, and

[6]The group *Research and think tanks* also includes international organizations and consultancies. The majority of *NGOs* focus on environmental topics. The *Industry* groups comprises potential users of hydrogen, but also producers. The analysis omits individuals that cannot be assigned to any actor group.

Table 2: Emerging conflicts

Enthusiastic:		Skeptical:
4. Use (191)		
Wide use (94):	⟷	Restricted use (97):
Private cars		Not private cars
Gas grid		DDI priority
Heat		Not heat
Wide application		Not gas grid
5. Production method (171)		
Non-green necessary (88):	⟷	Exclusively green (83):
Transition and market creation		Explicitly green only
Consider various colors		Only green carbon free
Only green not possible		CCS is contested
Include grey		Not green prolongs fossil fuel use
6. Imports (85)		
Imports beneficial (55):	⟷	Imports concerning (30):
Using beneficial solar conditions		Import dependency
Advantage for exporters		Disadvantage for exporters
Potentially cheap imports		

The table shows short versions of storyline related to the three emerging conflicts. The frequency of coded passages for each aggregated storyline is shown in brackets, sub-storylines are sorted descending by the frequency of coded passages. Storylines on the left are enthusiastic about hydrogen, those on the right skeptical.

Siemens). Other frequently occurring actors comprise NGOs (BUND, DUH, Klimaallianz) and research institutes (Max Planck Institute, Dena, Fraunhofer ISE). In some instances, single quotes are cited in multiple articles. This mostly applies specifically to statements by ministers, and the CEO of the German car manufacturer Volkswagen. Appendix A.2 provides the descriptive statistics about discursive engagement of all actors included to this analysis. Appendix A.3 describes the temporal development of the discourse and conflicting storylines.

3.5. Data analysis

We analyze the sample in two steps. In a first step, we descriptively analyze the storylines that refer to using hydrogen in general by comparing the shares of each actor group. In a second step, we apply DNA to analyze the three specific lines of conflict regarding the use, production method, and imports of hydrogen, based on codes of 21 storylines shown in Table 2.

We restrict the DNA to the most active actors, only including actors with at least three coded passages.[7] The sample thereby reduces to 257 coded storylines by 63 actors. We create an actor congruence network to visualize individual actors using similar storylines. Links between actors are normalized to account for unequal numbers of coded storylines between actors, by dividing the edge weight with the average number of storylines (Leifeld, 2017). Figure 3 shows the resulting discourse network in detail. Figure 4 (a-f) shows the same discourse network, but with all edges highlighted that include at least one storyline in support of the respective conflict position.

Data limitations resulting from the novelty of the discourse require consideration when interpreting our findings. Comprehensively understanding positions of individual actors based on their public statements is not possible for most actors, as sufficiently insightful text passages addressing multiple storylines are scant. The short analysis period, moreover, prevents analyzing dynamic changes of individual positions, although we know from our background

[7] Our inclusion criterion focuses on actors that are most visible in the overall discourse. We additionally created an actor congruence network that includes actors that most visible in the conflicts (in contrast to the overall discourse) by tightening the inclusion criterion towards at least three coded passages within the three conflicts. The resulting network shows a qualitatively similar pattern, but only includes roughly half of the actors, with particularly many missing actors from the grey shaded area.

interviews that positions of single actors have changed over time. A dynamic analysis could provide interesting insights, but thus remains for future research. We discuss further limitations to our study beyond data constraints in Section 5.3.

4. Results

We have identified six major topics in the German hydrogen discourse. Three topics address the deployment of hydrogen in general, and three are about specific conflicts. Next we present the general discourse (Section 4.1), then the conflicts (Section 4.2).

4.1. The general hydrogen discourse

The attention for hydrogen has very much increased since 2019 (see Appendix A.3), and there is a lively debate among a broad range of actors from different sectors and institutional backgrounds. Interestingly, we find many incumbent firms from e.g., energy, transport, and industry. In general, there is widespread support for hydrogen as a central energy carrier to achieve net-zero, and as a base for new technologies creating economic opportunities. At the same time, potential caveats receive attention as well.

We have grouped the storylines in the general discourse under three overarching topics: the role of hydrogen for climate change mitigation, economic considerations, and technical aspects. Coincidentally, each topic entails two enthusiastic, and one skeptical storyline. Figure 2 shows the relative shares of all nine storylines by actor group. The following paragraphs discuss each topic separately. A final paragraph discusses the overall relevance of the storylines, and condenses the actor positions.

The contribution of hydrogen to climate change mitigation is a key topic. Hydrogen being important for the energy transition, or required for net-zero, is frequently mentioned by policymakers, industry actors and think tanks. "*I am convinced that we cannot achieve the energy transition without gaseous energy sources. They are an indispensable part of the energy transition in the long term*" (BMWi, 63).[8] While NGOs do not necessarily disagree here,

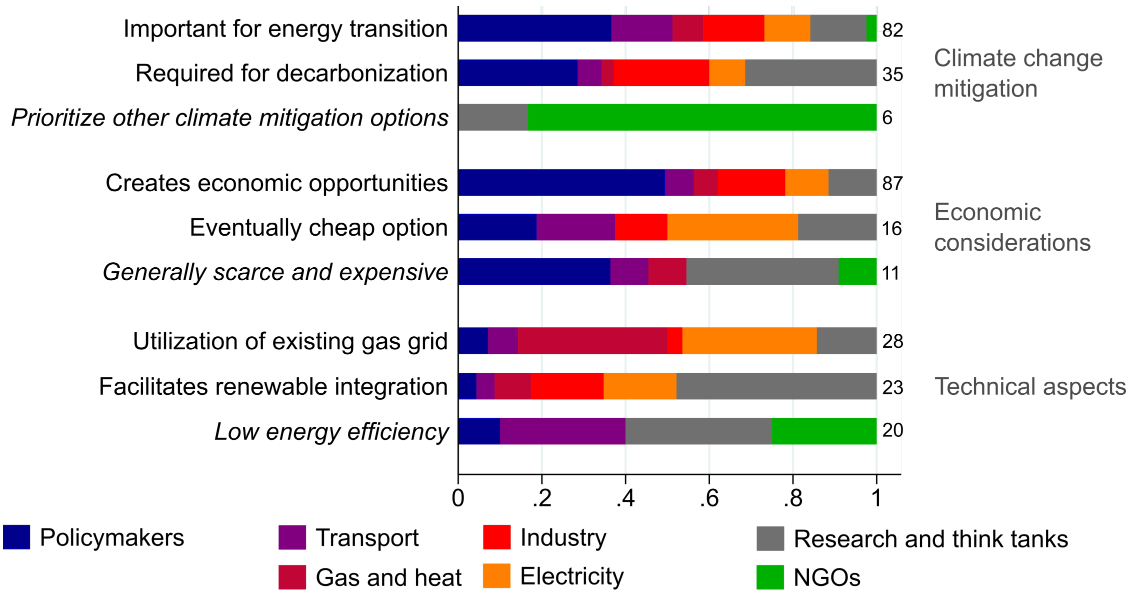
[8] The number corresponds to the list of newspaper articles in Table A.1, Appendix A.1.

they also mention that other climate mitigation options, such as efficiency or sufficiency, should be prioritized, or at least not be forgotten.

> *"At the moment, people like to pretend that there is an unlimited supply of hydrogen, for example from Africa. [...] We must continue to think about how we can use our resources more efficiently, which flights and which transports we can do without, without giving up our prosperity"* (BUND, 143).

But these more critical voices are a minority. In summary, we find that, actors generally agree that hydrogen is relevant for climate change mitigation, but not necessarily how it compares to other mitigation options.

Figure 2: General storylines



The figure shows the share of general storylines sorted by topic and aggregated actor group. The first two storylines of each topic are enthusiastic, the third takes a skeptical position (in italics). The frequency of manually coded passages is depicted next to the bars. Further information on the storylines is provided in Table 2.

Economic considerations constitute another key topic in the German hydrogen discourse. Emerging economic opportunities from establishing a hydrogen economy are frequently highlighted by policymakers across all parties and ministries, and incumbents from many different sectors. "*We want to become the hydrogen republic of Germany. [...] And we want Germany to become the world market leader in the production and use of green hydrogen obtained from renewable energies*" (BMBF, 123). While policymakers declare the goal of maintaining, or even strengthening Germany's role as a global technology exporter, we find that several industry actors, including both incumbents and newcomers, see business opportunities in the development and export of hydrogen technology, or hydrogen-based products, such as low-carbon steel. However, today hydrogen is very expensive, and especially researchers and green policymakers expect that hydrogen will remain scarce and expensive energy carrier in the future. "*Hydrogen is the caviar among energy carriers and is too expensive and valuable to be used everywhere*"(Green Party, 117). Some incumbents from various industry sectors disagree, arguing either that absolute generation costs for hydrogen will further decrease along with decreasing costs for renewable electricity, or that hydrogen will become relatively cheap when expecting further increasing carbon prices. "*The production of renewable energy, especially wind energy on the high seas, is becoming cheaper and cheaper, and at the same time the high CO2 prices, despite the Corona crisis, make coal in particular unprofitable*" (EU commission, 118).

Technical aspects are the third key topic in the discourse. Researchers and industry actors argue that hydrogen would facilitate the integration of variable renewable electricity by stabilizing and balancing the electricity grid. Incumbents from the gas, heat, and electricity sector mention that there could be benefits when the existing gas grid is used to transport and store hydrogen, such as large energy storage and transmission capacities, cost savings by using the existing infrastructure, and less demand for new publicly contested transmission electricity grids.[9] "*The gas customers of today are the hydrogen customers of tomorrow*" (FNB Gas, 147). While these storylines are largely uncontested in the discourse, there is some general critique around the low energy efficiency of green hydrogen production. Especially researchers and NGOs frequently make this point, highlighting electrification as a more efficient alternative to hydrogen.[10]

Comparing the relevance of storylines across topics shows that climate change mitigation and creating economic opportunities receive most attention. Technical aspects and storylines related to costs or the availability of hydrogen are less prevalent. Assessing the positions of

[9] The storyline encompasses both the German gas transmission grid and the distribution network, and comprises the options of blending natural gas with hydrogen, or completely converting existing natural gas pipelines to hydrogen. Conflicting views on blending natural gas with hydrogen, and using hydrogen for heating are separately discussed in Section 4.2.1.

[10] The high transport sector share almost exclusively stems from the CEO of the car manufacturer Volkswagen, who is frequently cited advocating for electric mobility in contrast to fuel cells.

actor groups shows that NGOs almost exclusively mobilize the three skeptical storylines. Policymakers emphasize the role for climate change mitigation, economic opportunities, but a few also mention that hydrogen will remain scarce and expensive. Industry actors are very much in favor of hydrogen. They emphasize that hydrogen will become cheap, and they highlight the option to utilize the gas grid. We discuss the role of incumbent actors in more detail in Section 5. The group of researchers and think tanks engages with all three topics.

4.2. Specific lines of conflict

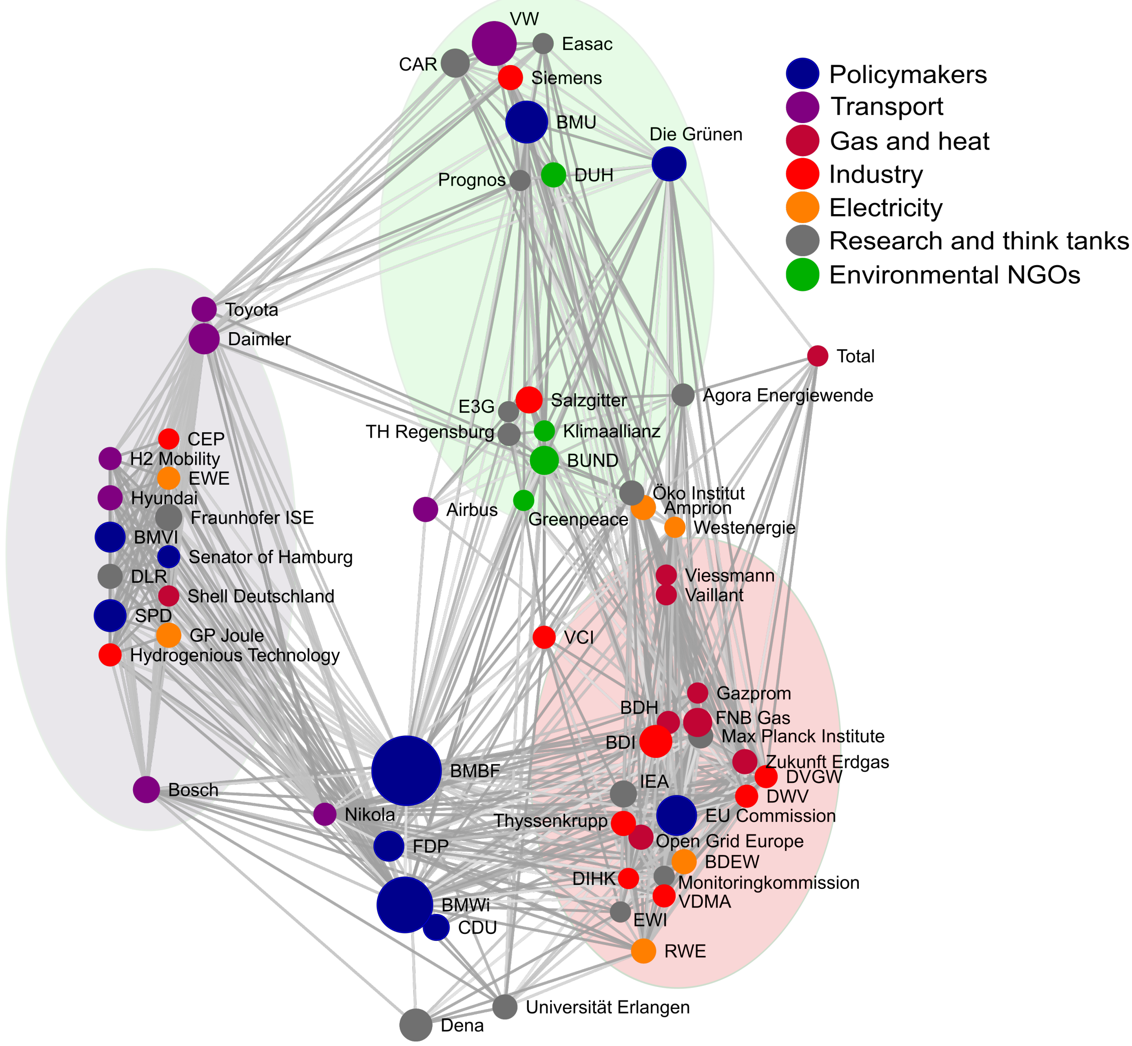
In addition to the overall support for hydrogen, we find three specific lines of conflict on where to use hydrogen, the production method, and imports. Regarding the use of hydrogen, actors disagree whether hydrogen should only be used in situations with little alternatives, for example in DDIs, or widely across many sectors. Regarding production, actors disagree whether hydrogen should be exclusively produced from renewable energies (green hydrogen), or whether fossil fuels, in combination with carbon-capture and storage technology, can also be used to temporarily produce blue hydrogen. Finally, actors have conflicting views regarding whether hydrogen imports are rather problematic, or beneficial. That imported hydrogen is required to satisfy Germany's future energy demand is uncontested.

We employ DNA to explore the actor positions around these conflicts in more detail. Figure 3 shows the actor congruence network for the storylines related to the three conflicts.[11] In the discourse network, actors are generally well connected, although there are different parts with particularly dense connections between actors. To support the interpretation of the network, we highlight three parts with shaded backgrounds. Each part includes actors from different groups, but some are more dominant than others.

The green area comprises NGOs, several research institutes and think tanks, policymakers from the German green party and the environmental ministry, a leading electric vehicle manufacturer (VW), and two leading industrial companies (Salzgitter and Siemens). The red area is dominated by incumbents from the gas, oil, power and heat sector. It also comprises the EU commission, researchers and think tanks, and actors from other industrial sectors.

[11] The actor congruence network hence only includes storylines on related to the use, production method, and imports as listed in Table 2.

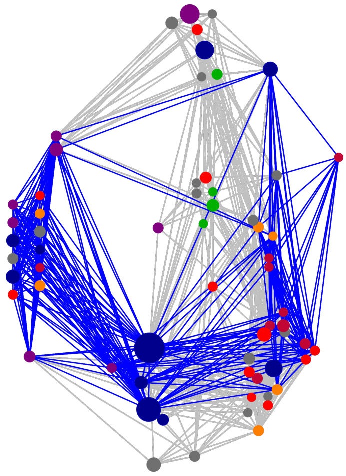
Figure 3: Discourse network of key conflicts in the German hydrogen debate



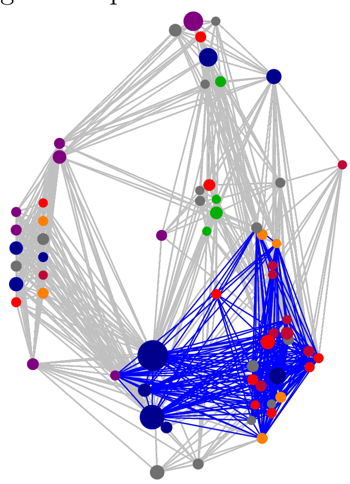
The figure shows an actor congruence network for the three conflicts on the use, production method, and imports of hydrogen. Nodes represent actors, edges represent shared storylines. The node-size correlates with the number of newspaper articles having at least coded passage for the respective actor. The grey shading of edges is darker for a higher normalized number of shared storylines. The node colors correspond to the actor groups, and the shaded areas highlight visually identified agglomerations. Overlapping nodes were manually disentangled (especially in the grey shaded area).

The grey area is dominated by actors from the automobile sector, several policymakers, think tanks and research institutes, and hydrogen interest organizations. Some actors, especially two dominant ministries and two parties, are between the shaded areas. The following sections discuss the three lines of conflict in detail. Figure 4 (a-f) highlights all edges that include at least one storyline in support of the respective conflict position.

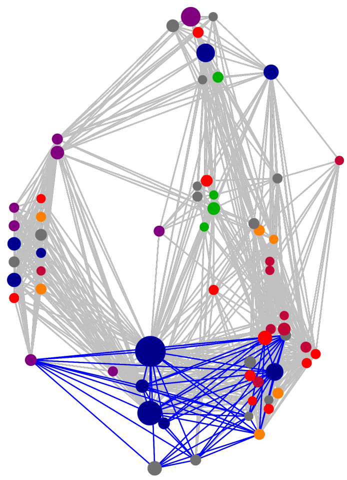
Figure 4: Specific lines of conflict



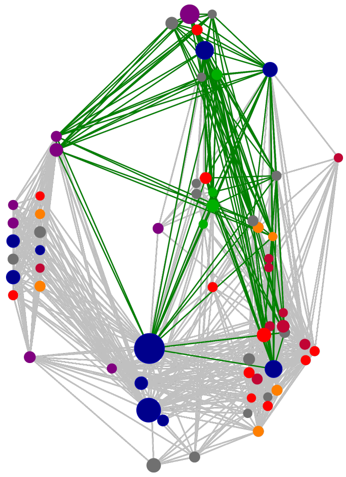
(a) Use: Wide use



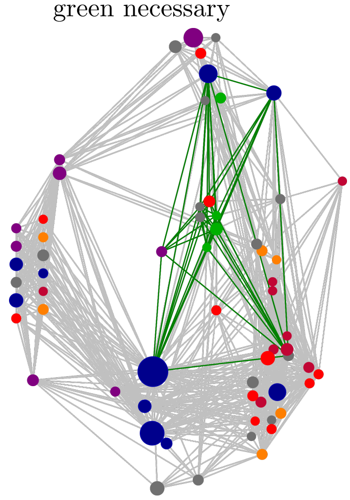
(b) Production method: Non-green necessary



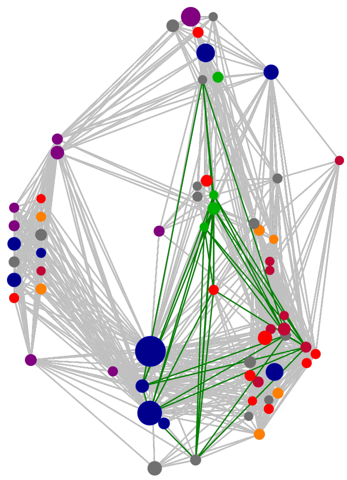
(c) Imports: Imports beneficial



(d) Use: Restricted use



(e) Production method: Exclusively green



(f) Imports: Imports concerning

The figures highlight edges with enthusiastic (blue) or skeptical (green) storylines with respect to the use (a,d), production method (b,e), and imports (c,f). The actor congruence networks are otherwise identical to that in Figure 3. Highlighted edges contain at least one storyline that is part of conflict position as indicated by the panel name (see Table 2 for more information).

4.2.1. Use

As a general pattern, most industry actors want to use hydrogen for their own sector. While many highlight their preferred use, only some actors argue that using hydrogen should be restricted. We classify storylines that envision using hydrogen for cars, blending it into the natural gas grid, heating, and a wide application in general, as 'wide use', and those that oppose one of these uses (cars, blending into gas grid, heating), or want to use hydrogen only for DDIs, as 'restricted use'. The specific arguments differ by application, but many outline potential benefits for the climate: "*In no other area than the heating sector would such large CO2 savings be possible so quickly and pragmatically*" (Viessmann, 144). Blending hydrogen into the natural gas grid "*[...] would make natural gas greener. All the investments have already been made, the pipelines work, the manufacturing plants exist*" (Total, 179). "*We need e-fuels and hydrogen from sustainable energy sources in order to achieve the climate targets for the millions of cars in our fleet*" (VDA, 156). Proponents of a wide use mostly comprise actors in the red and grey areas. Not surprisingly, actors in the grey area mostly emphasize using hydrogen for cars, while those in the red area propose heating, and blending hydrogen into the natural gas grid. The Green party is an outlier due to one quote from 2019 that promotes blending hydrogen into the natural gas grid. Their position has changed since, which is why it also features prominently among those that want a more restricted use.[12]

Those favoring a restricted use argue that hydrogen should primarily be used where there are little alternatives. The rationale behind this is that, if hydrogen can be used widely, it may be missing where it is needed most.

> "*The [steel] industry has no alternative if it wants to become climate-neutral. [...] The cement industry and the chemical industry are also dependent on hydrogen. In air and sea transport, hydrogen is also the central building block on the way to climate neutrality*" (BMU, 80).

Actors also explicitly mention applications such as private cars or heating in which hydrogen should not be used. "*Green hydrogen has no place in cars and heating systems*" (DUH, 104). Storylines in favor of a restricted use are very prominently promoted by actors in the green area, but also by the Max Planck institute or the EU Commission, that are located in the red area. The EU explicitly prioritizes hydrogen for industrial uses. Toyota and Daimler (in the grey area) are also noteworthy, as both predominantly promote hydrogen for trucks or buses, not for private cars.

[12] Also other actors communicate contradicting storylines, which can be explained by different individuals being aggregated to one actor, a temporal change in the actor's position, or simply inconsistent communication.

4.2.2. Production method

In the discourse on how to produce hydrogen, two major arguments dominate. One is about only producing hydrogen from renewable energies, and the other is about making large quantities of hydrogen available quickly by additionally using fossil fuels. Many actors argue that blue hydrogen is required for a transition period, or simply state that various forms of production should be considered. "*Hydrogen has many colors, and we should use all. [...] We should use blue or turquoise hydrogen for a transition period*" (RWE, 115).[13] A variation of this argument is that only green hydrogen would not be possible due to limited availability or high costs. A minority even considers grey hydrogen as a temporary solution. Those in favor of blue hydrogen include almost all actors in the gas and heat sector, several policymakers, and also a leading environmental research institute: "*[I]n the next decade [blue hydrogen will] be the only source that is justifiable in terms of cost for high-volume applications and for the market ramp-up in those areas in which hydrogen is of high strategic importance*" (Öko-Institut, 171). Also the EU Commission promotes using blue hydrogen.

Proponents of green hydrogen argue that only green hydrogen will actually be carbon free. Others mention that carbon capture and storage (CCS) is a contested technology: "*Why should we use blue hydrogen in the future, if the climate footprint is bad and the costs for generation high? [...] It instantly brings a debate about CCS [...], which is predominantly rejected in Germany*" (BMU, 80). A few also highlight that using blue hydrogen would be a lifeline for the fossil fuels: "*Blue hydrogen is of fossil origin and perpetuates the fossil industry instead of transforming it*" (TU Regensburg, 112).[14] These storylines are predominantly used by actors in the green area. The ministries for the environment and for education and research have both supported green hydrogen in the German hydrogen strategy, whereas the economics ministry promoted to also include blue hydrogen. Salzgitter, a leading steel producer, also promotes using green hydrogen for its steel production, and even to produce it by themselves with their own renewable electricity.

[13] One storyline of (a) states that "blue hydrogen was required for a transition period or building up the market, but that green hydrogen would be the ultimate goal". This storyline is practically in between both extremes. However, our distinction follows the guiding idea to disentangle which actors would support building hydrogen infrastructure for non-green hydrogen as well, and those who disagree.

[14] Given that it would be unclear whether the CO2 will remain underground for a 1000 years, he adds that "*Blue hydrogen is actually also only grey hydrogen*".

4.2.3. Imports

Actors arguing that hydrogen imports are beneficial explain that hydrogen generated abroad would profit from better solar conditions and is hence potentially cheaper, or that exporting countries would benefit.

> "*With green hydrogen, the geographical advantages in renewable energies could become a development engine for the societies there [Africa]. [...] In this way, we not only create the basis for German technology exports, but also ensure a climate-friendly energy supply*" (BMBF, 61).

Benefits of hydrogen imports are promoted by the BDI as a leading industry association, the EU Commission, and several research institutes in the red area, as well as by several policymakers, and Bosch, as part of the grey area.

Those concerned of hydrogen imports warn of new import dependencies, and of potential environmental and social risks for exporting countries. "*Importing hydrogen from countries of the Global South without adequate consideration of the ecological and social situation in the country of production risks being perceived as a mechanism of exploitation or a new form of colonialism*" (Brot für die Welt, 173). The following quote addresses the risk of import dependency: "*Many of the countries that basically come into consideration still have to develop themselves first. [...] They would not export the green hydrogen, but use it for their own economic development*" (Zukunft Erdgas, 79). Concerns about imports are mostly raised by policymakers, NGOs and research institutes. Risks for exporters are highlighted by NGOs and members of the German liberal party (FPD), while some incumbents (Zukunft Erdgas and VCI) warn of import dependency.

4.3. Summary of results

The German hydrogen discourse is characterized by a strong agreement across a broad range of actors acknowledging that fostering hydrogen is necessary for achieving net-zero. Policymakers highlight economic opportunities and the importance of hydrogen for climate change mitigation. Incumbent industry actors from different sectors are also very much in favor of hydrogen and stress multiple benefits of a hydrogen economy. Especially NGOs, researchers and think tanks, in contrast, argue that hydrogen is expensive, inefficient, and that its potential is overestimated.

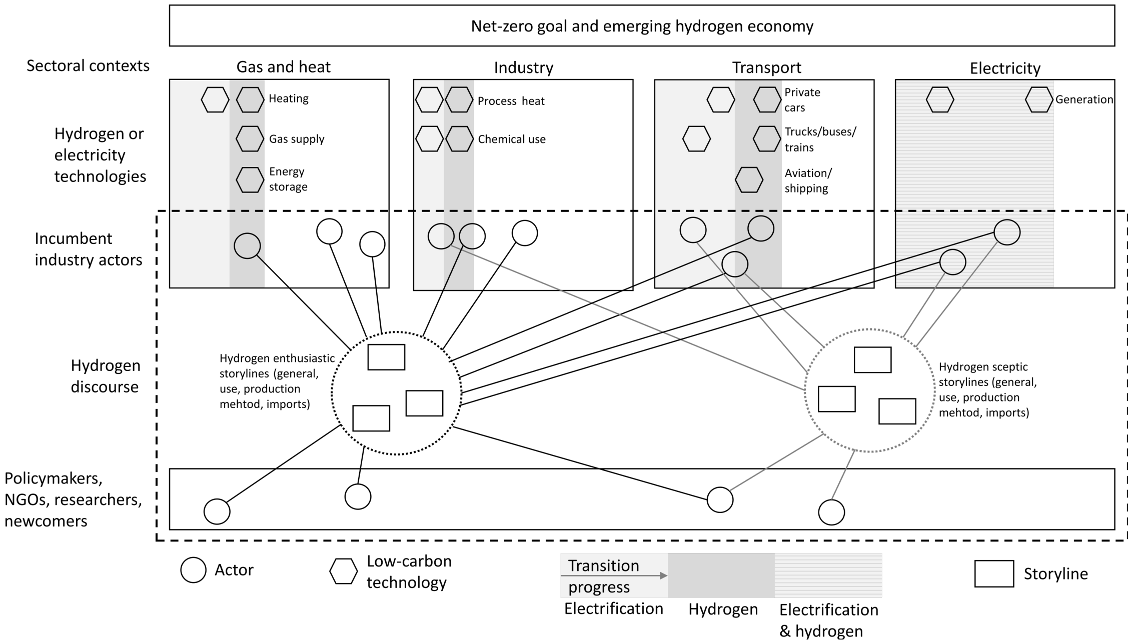
A first conflict is about what to use hydrogen for. While a few steel and power incumbents as well as NGOs favor a restricted use, most incumbents also want to use hydrogen for individual transport and heating. The second major conflict is about the production method. Especially gas and heat sector incumbents promote using blue hydrogen, at least for a transition period, while NGOs, the ministry for the environment, and the Green Party exclusively support green hydrogen. The third conflict concerns potential risks and benefits of hydrogen imports. Both are addressed by policymakers. While most incumbents regard imports as beneficial, there are others warning of import dependencies. NGOs also emphasize risks for potential exporters.

The positions towards the conflicts seem partially correlated. Actors in the green area promote using exclusively green hydrogen and favor a restricted use. This cautious approach seems intuitive, given that the green cluster is dominated by NGOs. Most actors in the red and grey areas consider non-green hydrogen necessary, and prefer a wide use. These positions seem plausible as they match with the respective interests, e.g. using the existing gas grid or having large quantities of hydrogen quickly available. With respect to imports, actors in the red area seem divided. From the green or grey areas, only a few actors refer to imports at all. In the next section, we will continue to explore potential motivations of actors from different economic sectors to support hydrogen, and taking specific positions in the conflicts.

5. Discussion

Our findings show that many incumbents from different sectors and industries support the idea of establishing a hydrogen economy in Germany. This outcome is surprising, given that numerous prior studies on energy transitions have shown that resistance toward low-carbon innovations typically comes from incumbent actors (Geels, 2014; Smink et al., 2015; Johnstone et al., 2017; Isoaho and Markard, 2020), and when considering their different sectoral backgrounds. To explain these puzzles, we apply the framework presented in Section 2.5 to our case with four different sectors (see Figure 6). Table 3 complements the figure by providing background information on the different *sectoral contexts*, *sector-specific technology* features (including the availability of alternatives to hydrogen), and *actor interests*.

Figure 6: Applied conceptual framework



The applied conceptual framework positions actors in the sectors gas and heat, industry, transport, and electricity in a stylized manner in the discourse. The sectors are at different transition stages towards using technologies based on electricity or hydrogen. The depicted technologies only build a selection to illustrate the overall picture. The different low-carbon technologies are competing, except for the electricity sector, where both complement each other. In line with our empirical analysis, we only focus on the discourse on hydrogen.

Table 3: Sectoral transitions

Sector	Sectoral context	Sector-specific technologies	Actor interests
Gas and heat	Hydrogen: Transition at an early-medium stage. Increasing public and political pressure to decarbonize the building sector and phasing-out natural gas. Policies are under development, upcoming regional feed-in of hydrogen to gas grids. Potential for local and national power storage. Energy transport via pipeline to avoid contested deployment electricity deployment of transmission power grid. Electricity: Transition at medium stage. Low-carbon heating supported by public funding schemes.	Hydrogen: Heating via blending hydrogen into existing natural gas grid, or redesigning natural gas infrastructure. Large potential energy storage and transmission capacities in existing gas infrastructure. Infrastructure potentially needed for gas supply of combined heat and power generation (see Sector Electricity). Electricity: Heat-pumps are economically competitive and increasingly deployed.	Hydrogen: Strong support by incumbents, as hydrogen only option to sustain current business models, with potential of blue hydrogen to save natural gas assets. Electricity: Not supported by incumbents as outside current business models. Yet, supported by other actors manufacturing heat-pumps.
Industry	Hydrogen and Electricity: Transitions at early stages. Difficult-to-decarbonize industries, such as steel, chemical and cement industry, of increasing political focus. Some industries under strong international competition. Hydrogen considered primary solution, large public transition funding envisaged e.g. via carbon-contracts for difference.	Hydrogen and Electricity based technologies still under development. Hydrogen for production processes requiring high temperatures and chemical properties of energy carrier, electricity only for high temperatures.	Hydrogen and Electricity: Incumbent actors generally support using hydrogen or electricity, depending on industrial process and political support. No newcomers involved.

Transport	Hydrogen and Electricity: Especially road transport under increasing decarbonization pressure due to national and EU regulation. Often both hydrogen and electricity technically possible. Hydrogen: Transition at early-medium stage. Fuel cell cars scarcely sold. First commercial projects for heavy transport and trains. First pilot projects for shipping and aviation. Electricity: Transition at medium stage. Battery electric vehicles with increasing market shares, increasing charging infrastructure. First commercial projects for heavy transport and trains. No option for aviation, first pilot projects for electric ships.	Hydrogen: Fuel cell cars fully developed but expensive. Fuel cell trucks, buses and trains developed. Technology for aviation and shipping under development. Electricity: Battery electric vehicles fully developed. Electric trucks, buses and trains developed. No option for aviation, ships for short distance under development.	Hydrogen: Support ranges from weak to strong, depending on application, and individual decisions by companies on specific technology. Support generally weaker for smaller and lighter vehicles. Incumbents challenged by newcomers (e.g. Nikola). Electricity: Support inverse to hydrogen, generally stronger for smaller and lighter vehicles. Incumbents challenged by newcomers (e.g. Tesla).
Electricity	Special context: Energy carriers complementary, electricity primary option. Electricity: Transition at medium-late stage: Share of renewable energies increases, although deployment slowed down by local resistance and lengthy project implementation. Coal phase-out decided, natural gas increasingly less of considered transition option. Hydrogen: Thus far, no commercial power production based on hydrogen, only expected for energy systems with high shares of renewables.	Electricity: Renewable energies generate power, most importantly PV and wind. Hydrogen: Natural gas power plants available for power generation to balance electricity grid, but need adjustment for hydrogen.	Electricity: Support by most incumbents as portfolio now includes renewable technologies. Demand adjusted regulations for faster deployment of renewables. Hydrogen: Support by some incumbents as new business field through green hydrogen production.

The table describes the *Sectoral context*, *Sector-specific technologies*, and *Actor interests* in the sectors Gas and heat, Industry, Transport, and Electricity.

In the following, we first discuss separately for each sector, how its context and technology options contribute to explaining the interests of incumbent actors and their positions in the discourse (see Section 5.1). We then outline broader implications of our findings for transition research covering multiple sectors and technologies, and how this may affect positions of actors more generally (see Section 5.2). We finally discuss limitations to our approach (see Section 5.3).

5.1. Sectoral transitions

Gas and heat sector incumbents are among the most vivid supporters of a large hydrogen economy. Using hydrogen widely would increase the demand for hydrogen infrastructure, and thus enable incumbent gas firms to use their existing gas grids for hydrogen transport. Incumbent manufacturers of gas boilers also see an opportunity in hydrogen, as they are challenged by heat pumps as an alternative to conventional boilers. Incumbents from the gas and heat sectors hence actively mobilize storylines in support of using the existing gas infrastructure, promote hydrogen for heating, and blending it into the gas grid. New hydrogen pipelines would constitute a novel business opportunity, and vertically integrated gas suppliers could use their natural gas sources to produce blue hydrogen. This is why they argue that blue hydrogen will be required for a transition period, and highlight the benefits of hydrogen imports.[15]

Incumbents of Germany's energy intensive industries, covering most importantly the steel, chemical and cement industry, promote using hydrogen to decarbonize. These industries are under pressure to decarbonize production processes, but they can expect financial public support for the transition (BMWK, 2022). Hydrogen is frequently highlighted as a key, or even only solution to decarbonize fossil fuel based production processes that currently require specific chemical properties, while other processes requiring high temperatures may also be decarbonized via electricity (Madeddu et al., 2020). Incumbents generally support the idea of establishing a hydrogen economy, and suggest a fast ramp-up of hydrogen. For example, an important industry association (BDI) supports blue hydrogen for a transition period, but

[15] Analyzing the discourse on natural gas for power and heat generation is beyond our scope. However, the narrative of natural gas being a "bridge fuel" strongly links to hydrogen, as the "hydrogen readiness" of new natural gas power plants is used as a major justification for their continued deployment.

does not want to use it for heating, potentially because of limited supply. Yet, some industry actors promote only using green hydrogen as they diversify their business models towards becoming producers of renewable electricity and green hydrogen, thus taking a dual role of using and producing hydrogen. Viewpoints on imports diverge, as the BDI expects benefits due to lower costs, while the chemical industry association (VCI) fears import dependencies.

Incumbents in the transport sector are divided between supporting hydrogen or electricity. The sector is rather complex, as it comprises different modes of transport, having different technological options and peculiarities. Hydrogen based fuels have advantages for applications that require a high energy density (relative to weight or volume), and is thus the preferred solution for airplanes and ships, while for trains and trucks both hydrogen and electricity are feasible options. All modes of transport require low-carbon solutions, but especially road transport is under increasing domestic and European pressure to decarbonize. Incumbents are also challenged by newcomers, such as Tesla or Nikola. The German car industry has supported fuel cell cars in the past, but increasingly turns to battery electric vehicles.[16] Some car incumbents, such as Daimler, also follow a dual strategy and focus on battery electric private cars, but hydrogen for trucks.[17] In the discourse, incumbent actors mostly discuss specific and often technological aspects of their transport mode (e.g. charging infrastructures, or potential distances), or discuss the potential of hydrogen for decarbonizing a specific transport mode. Statements on the production of hydrogen or imports are largely absent.

Actors in the electricity sector generally support the deployment of hydrogen. The sector faces ambitious targets for the renewable electricity generation. In contrast to all other sectors, in which renewables and hydrogen based technologies compete, they are complementary in the electricity sector. The envisaged use of hydrogen is to balance demand and supply of electricity generated by increasingly deployed fluctuating renewables. Renewable electricity is moreover an input for domestically produced green hydrogen. Surprisingly, despite mainly

[16] Volkswagen as an early proponent of battery electric vehicles, and an outspoken opponent of using hydrogen for private cars, builds a notable exception.

[17] Fuel cell cars never obtained a higher market share, while that of battery electric vehicles rapidly increases. However, some still argue that electric vehicles may dominate in the short-medium term, but that fuel cell cars would become the dominant long-term solution.

focusing on producing green hydrogen themselves, incumbent power companies also promote blue hydrogen for a transition period, and using hydrogen for heating.

5.2. Implications for transitions research

Our analysis has shown that transitions toward net-zero create new challenges for established frameworks and perspectives in transition studies.

First, we need to embrace multi-system interactions and multiple transitions unfolding in parallel across different sectors (Rosenbloom, 2020; Kanger et al., 2021). In the case of hydrogen, we are confronted with transitions in electricity, transport, heating and industry. Each sector has its own specificities in terms of actors and their interests, regime structures, sustainability challenges and potential solutions. Also, sectors are in different transition stages. In Germany, the electricity sector has already transformed quite substantially, while the net-zero transition in the industry sector is only beginning. These transitions may complement each other, but they may also compete, for instance when scarce resources are needed for different applications in different sectors. In our study, we caught a first glimpse of this competition in the debate about where to use hydrogen. Other phenomena are that multi-sector transitions may blur the boundaries between sectors, or create entirely new industries. Our conceptual framework is a first step to capture (some of) the complexity of multi-sector transitions.

Second, we need to consider multi-technology settings characterized by complex interactions between technologies at different stages of maturity and different levels of disruption (Papachristos et al., 2013; Andersen and Markard, 2020). In this case, hydrogen and electricity can be the basis for many new low-carbon technologies. These constellations may lead to complex interactions with complementarities (e.g., renewables and hydrogen in the electricity sector) and competition (e.g, electric vs. hydrogen vehicles). We also find that, depending on existing assets or prior investments, hydrogen may be perceived as non-disruptive (e.g., in the gas and heat sector, where existing infrastructure can be used), while it may be more disruptive elsewhere (e.g. in the industry sector). Our applied conceptual framework reduces this complexity by its primary focus on hydrogen, but also points towards the competition with electricity in each sector. Future studies may develop more holistic approaches that analyze several technology options together.

Third, the next generation of frameworks needs to accommodate a broad variety of actors from different sectors with different strategic interests. Our analysis showed that incumbents' view on hydrogen seems to be affected by their sectoral background, the performance and (non-) disruputiveness of new sector-specific technologies, and prior strategic decisions. We observed the following five relations towards hydrogen. First, in sectors where hydrogen is (currently) the only low-carbon option, it finds broad support (e.g. for different industrial processes, aviation and shipping). Second, actors also support hydrogen, if it complements existing technologies (e.g. electricity sector). Third, hydrogen receives very strong support, if it is compatible with the status quo business of incumbents, especially where this is threatened by electricity (e.g. gas and heat sector). Fourth, hydrogen receives general support of actors independent of a sector when it constitutes a new business opportunity (e.g. all firms that want to manufacture hydrogen production technology). Finally, the relation is ambiguous in sectors without a clearly preferable technology (e.g. road or rail transport, or industrial heating). Then, prior strategic decisions of individual companies may be key for understanding the viewpoint of actors. Future frameworks could explicitly categorize similar relations, which for us constitute an unexpected outcome of the study.

5.3. Limitations

Our study is subject to the following limitations. First, focusing on Germany as a single country with specific peculiarities complicates creating generalizable findings. For example, the German hydrogen strategy envisages large-scale hydrogen imports, and supports exclusively green hydrogen. Discourses will likely differ in countries that, for example, envisage exporting hydrogen, or that would benefit from producing blue hydrogen using domestic natural gas resources. Second, we only analyze the discourse on hydrogen, but neglect interrelated discourses on other net-zero options, for example technologies based on electricity, or negative emission technologies. Obtaining a deeper understanding of how actors position towards hydrogen, and net-zero in general, would require a broader analysis scope. Third, data limitations prevent a more comprehensive analysis of actor positions and discourse analyses over time.[18] Fourth, we only analyze the public discourse, and thereby omit other discourses and data sources, for example in the parliament, or expert discourses. Especially position papers could be a particularly insightful complementary data source.[19]. Finally, the storylines rather strongly aggregate distinct statements to provide a comprehensive overview, which, however, leads to neglecting sector-specific debates, and nuances of different arguments. For example, we omit the prominent sector-specific debate on fuel cell cars vs. battery electric vehicles, as well as similar debates for other sectors and applications. Future studies could analyze larger bodies of data using e.g. machine-learning based coding techniques to compare hydrogen discourses across different countries, or to consider multiple net-zero technologies. Social media data might be particularly suitable for dynamic discourse analyses.

6. Concluding remarks

The transition toward net-zero calls for an economy-wide decarbonization and new strategies and technologies. This creates new challenges for policy and research. One challenge is that multiple transitions unfold in parallel, which means that policies as well as conceptual frameworks have to address the ensuing interdependencies. The discourse around hydrogen shows some of these new complexities. We find a broad range of actors, including many incumbent firms from different sectors and with diverging preferences for specific technology solutions, expressing their demands, preferences and concerns. Most interestingly, we see many incumbent actors (for various reasons) supporting the development of a hydrogen economy, while environmental NGOs and several think tanks are less enthusiastic. We explain these seemingly surprising findings with sector-specific constellations of low-carbon alternatives and transition progress as well as firm-specific strategic decisions. Our conceptual framework helps to untangle and identify different levels (sector, technology, firm), different elements at each level (e.g. multiple sectors) and some key parameters (e.g., transition stage, availability of technology alternatives, strategic decisions) affecting the views of actors expressed in the public discourse.

[18] We describe arising limitations due to limited data in Section 3.5.

[19] An analysis of the German hydrogen debate based on positions papers is currently conducted by [blinded reference]

Our study, however, is just one step to address the complexity of multi-sector transitions posing new political and conceptual questions. For example, accelerating transitions to reduce emissions as quickly as possible need new infrastructures, which may create new path-dependencies and potential lock-ins. Also, we might see competition among sectors or firms over low-carbon energy carriers, such as hydrogen and renewable electricity, but also over public funding, or scarce resources. The high speed and wide scope to accomplish the transition toward net-zero will also confront us with the fundamental question, whether supply side responses, such as replacing fossil fuels with electricity or hydrogen, may need to be complemented with demand side strategies, such as promoting more sustainable lifestyles. With our study we have only begun to touch upon such issues. To understand the net-zero energy transition in its full complexity, it thus needs further research and the development of new analysis frameworks.

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A. Appendix

A.1. Search query and newspaper articles

We obtain the newspaper articles for our analysis by conducting a systematic search across different databases. The query includes articles with hydrogen mentioned at least once at the beginning, and four times in the main text. We only include articles that exceed 300 words. The precise time period ranges between the 01.01.2016 and 31.12.2020. Unrelated articles are removed from the search via a number of characteristic keywords. The following search query was used for the database Lexis, from where we obtain articles for *Die Welt*, *Frankfurter Allgemeine Zeitung* and *TAZ*:

hlead(Wasserstoff*) AND ATLEAST4(Wasserstoff*) AND Publication(Frankfurter Allgemeine Zeitung OR taz OR Die Welt) AND länge>300 AND date > 12/12/2015 AND date < 31/12/2020 AND NOT (Fusion* OR Zirkon OR Neutron* OR Helium OR Antimaterie OR myon* OR Deuterium OR Sterne OR MRT OR Wasserstoffperoxid OR Graphen OR Wasserstoffbombe OR Stempelzelle OR "Kryo-Wasserstoff") AND NOT Publication(Die Welt Hamburg)

The queries for WISO (*Handelsblatt*) or the *Süddeutsche Zeitung* archive are analogue, except for the following deviations: WISO prevents including a "*" to the query element that sets a minimum number of keyword mentions, resulting in potentially less findings. The Süddeutsche Zeitung query only receives articles with the keyword mentioned in the article title, without the option to set a minimum requirement for keyword mentionings in the full text, leading to potentially more findings.

They searches yield 321 articles in total. The articles split as to newspapers as following: *FAZ* 103, *Handelsblatt* 75, *SZ* 61, *Die Welt* 49 and *taz* 33. The final sample of 179 articles emerges after removing i) 3 articles from 2015, ii) 21 duplicates or false hits, iii) 34 articles without any content code, iv) 57 articles that only contains codes by journalists or actors omitted from the analysis, and, finally, v) 30 articles that exclusively contained storylines omitted from the analysis. The number of storylines thereby reduces from almost 4000 initially coded passages, to 614 in the final analysis, mostly during step iv) and v). The same storyline can be activated only once per article by the same actor. Table A.1 lists all newspaper articles.

Table A.1: Newspaper articles

N	Date	Newspaper	Title
1	1/29/2016	SZ	Gefesselte Energie
2	3/9/2016	Handelsblatt	Taktgeber für Technik
3	4/13/2016	Die Welt	Nur heiße Luft; Der Verkehrsminister will Wasserstoff-Autos fördern. Doch die Strategie ist ein Aufguss alter Pläne
4	5/6/2016	Handelsblatt	Thomas Bystry; 'Es sind nicht mehr viele Fragen offen'
5	5/6/2016	Handelsblatt	Die vergessene Alternative
6	5/20/2016	SZ	Wasserstoff marsch!
7	6/1/2016	SZ	Rohstoff Wind
8	8/16/2016	Die Welt	Linde steigt ins Carsharing-Geschäft ein; Gasekonzern will Wasserstoff als Antrieb für Autofahrer erlebbar machen
9	10/29/2016	taz	Weg vom Ölhahn; Lückenfüller Solar- und Windstrom lässt sich dezentral in Wasserstoff umwandeln und nach Bedarf wieder verstromen
10	12/14/2016	Die Welt	Anschub für das Wasserstoffauto; Bis 2026 investiert der Bund 250 Millionen Euro in die neue Technologie. Forschung und das Tankstellennetz sollen gefördert werden
11	12/24/2016	SZ	Ende einer Dienstfahrt
12	1/18/2017	SZ	Wasserstoff marsch!
13	3/24/2017	Die Welt	In Jülich geht die Supersonne auf; 150 Hochleistungsstrahler liefern Licht für Forschung
14	4/27/2017	FAZ	Im Wind stecken große Energiereserven; Das Ideal der Energietechniker bleibt der Wasserstoff
15	8/7/2017	Die Welt	Wasserstoff statt Diesel?; Der Abgas-Skandal erschüttert Deutschland. Verbrennungsmotoren werden infrage gestellt, E-Autos als Alternative gelobt. Doch eine saubere Technologie ist in Vergessenheit geraten
16	9/9/2017	SZ	Batterie gegen Brennstoffzelle
17	11/18/2017	taz	Die Reichweite ist kein Hemmnis; Batteriefahrzeuge stellen erhebliche Anforderungen an die Infrastruktur. Für das Netz wären Elektroautos auf Wasserstoffbasis dienlicher. Diesen kann man erzeugen und speichern, wenn Strom aus erneuerbaren Quellen im Überfluss vorhanden ist
18	11/18/2017	SZ	Dampf im Auspuff
19	3/3/2018	SZ	Kraftwerk auf vier Rädern
20	4/4/2018	Handelsblatt	Klimaschutz - Die andere Energiewende
21	6/21/2018	FAZ	Ein Sicherheitsnetz für die Energiewende
22	10/25/2018	FAZ	Japan prescht voran beim Ausbau der Wasserstoff-Tankstellen; Auch die Koreaner setzen stark auf diese Technologie
23	10/25/2018	FAZ	Great Wall und die deutsche Brennstoffzelle

24	12/10/2018	taz	Windstrom zu speichern ist effizient, aber teuer; Deutschland hat bereits drei Dutzend Power-to-Gas-Anlagen. Sie sind attraktiv und zuverlässig, doch Preisrückgänge wie bei Photovoltaik sind unrealistisch
25	1/30/2019	taz	Chemieriese ohne Futter; Wenn es nach den Beschlüssen der Kohlekommission geht, dürfte das Kohlekraftwerk in Stade nicht gebaut werden. Es soll den Chemiekonzern Dow Chemical mit Energie versorgen. Niedersachsens Umweltminister Olaf Lies (SPD) setzt auf Wind und Wasserstoff
26	2/2/2019	SZ	Knallgas im Tank
27	2/12/2019	FAZ	Windstrom zu Wasserstoff
28	3/7/2019	Handelsblatt	Daniel Teichmann; Der Wasserstoff-Mann
29	3/21/2019	Handelsblatt	CO2 - Vermeidung; Kalkulierter Klimaschutz
30	4/6/2019	Die Welt	Der blaue Weg; Viele betrachten das Elektroauto als einzige Option für die Zukunft des Automobils. Doch inzwischen mehren sich die Stimmen, die den Wasserstoffantrieb als Alternative sehen. Unser Autor hat getestet, ob die Anhänger der Brennstoffzelle recht haben
31	4/13/2019	taz	Ein Klassiker kommt in Fahrt; Wasserstoff ist ein altbekannter Energieträger. Doch erst jetzt können Forscher sein ungeheures Potenzial für das Gelingen der Energiewende richtig nutzen und arbeiten daran, die alte Idee der Brennstoffzelle zukunftstauglich zu machen
32	4/27/2019	SZ	Gas ohne Abgas
33	5/4/2019	FAZ	Wettlauf um den Elektroantrieb
34	5/15/2019	FAZ	Die Stahlproduktion soll grüner werden
35	5/25/2019	Die Welt	Mit Wasserstoff zur Wärmewende; Der Heizungshersteller Vaillant muss sich umstellen. Klimaschutzdebatte und Dekarbonisierung fordern zügiges Handeln
36	6/17/2019	Handelsblatt	Großes Werben für Wasserstoffwirtschaft
37	6/24/2019	Handelsblatt	Alles eine Frage der Geduld
38	6/24/2019	Handelsblatt	So funktioniert Industriepolitik
39	7/2/2019	Handelsblatt	Mobilität; Die Mischung macht's
40	7/16/2019	Die Welt	Siemens setzt in Görlitz jetzt auch auf Wasserstoff; Konzern plant mit Freistaat Sachsen und Fraunhofer-Gesellschaft einen Innovationscampus - inklusive eines Labors zur Forschung an klimafreundlicher Technologie
41	7/16/2019	Handelsblatt	Fraunhofer und Siemens bilden Wasserstoff-Allianz
42	7/18/2019	taz	Brennstoffzelle besiegt Tesla und Elektro-Audi; Eine Studie des Fraunhofer-Instituts zur Elektromobilität zeigt: Bei großen E-Autos ist die Wasserstoff-Technologie aus Sicht des Klimaschutzes vielen Batteriefahrzeugen überlegen
43	7/19/2019	taz	Antrieb Wasserstoff; Schwarze Ministerin für grünen Wasserstoff
44	7/29/2019	Die Welt	Warum Wasserstoff gegen den E-Motor chancenlos ist; Ist das Elektroauto wirklich die beste Alternative? Viele hoffen auf die Brennstoffzelle. Eine neue Studie jedoch macht wenig Mut

45	7/30/2019	FAZ	Wie klimaverträglich ist Wasserstoff wirklich?
46	8/3/2019	FAZ	Die neue Farbenlehre der Energiewende
47	8/10/2019	Die Welt	Heizen mit Wasserstoff; Die Gasheizung wurde als Ursache von Emissionen in Großbritannien lange nicht thematisiert. Doch jetzt soll ein Großversuch zeigen, dass es eine umweltfreundliche Alternative gibt. Vorteil: Das bisherige Netz lässt sich nutzen. Gebraucht wird nur ein neuer Boiler
48	8/15/2019	FAZ	Wasserstoff ist gut - aber schwer einzuführen
49	9/7/2019	taz	Grünes Gas im Chemiepark; Gut Ding braucht bekanntlich Weile. So auch die Wasserstoffproduktion aus Windstrom in Brunsbüttel, die Anfang August startete. Der regionale Versorger betreibt ein 20 Kilometer langes Gasnetz und will neue Wege gehen
50	9/12/2019	Die Welt	Die Suche nach der blauen Alternative; Bei der IAA dreht sich scheinbar alles um Batterieautos. Doch im Hintergrund schwelt der Streit um eine zweite Option - den Wasserstoff-Antrieb. Der jedoch hat einen vehementen Kritiker
51	9/13/2019	Handelsblatt	Mehr Tempo bei der Energiewende
52	9/14/2019	Die Welt	Streit um die Wasserstoff-Idee; Volkswagen-Chef Herbert Diess glaubt nicht an die Zukunft der Technik. Niedersachsens Ministerpräsident Stephan Weil widerspricht - trotz des Sitzes im VW-Aufsichtsrat
53	9/16/2019	Handelsblatt	Altmaiers Wasserstoffwette
54	9/17/2019	Handelsblatt	Japan; Weltmacht auf Wasserstoff
55	9/25/2019	Handelsblatt	Wasserstoff für jeden
56	10/5/2019	FAZ	Wasserstoff soll die Energiewende retten
57	10/8/2019	FAZ	Oben ohne
58	10/17/2019	Handelsblatt	Der Traum vom grünen wird Wirklichkeit
59	10/29/2019	FAZ	Lastwagen mit Wasserstoff im TankF
60	11/4/2019	Handelsblatt	Neuer Schub für grünen Wasserstoff
61	11/4/2019	Handelsblatt	Der Stoff der Zukunft
62	11/5/2019	Handelsblatt	Problemlöser Wasserstoff
63	11/5/2019	FAZ	Wir müssen bei Wasserstoff die Nummer 1 in der Welt werden
64	11/16/2019	SZ	Zu Wasser, zu Lande, in der Luft
65	11/25/2019	Handelsblatt	Klimaneutralität; Überlebensfrage für die Industrie
66	11/25/2019	Handelsblatt	Andreas Pinkwart; 'Klimaschutz geht nur mit der Industrie - nicht gegen sie'
67	11/25/2019	FAZ	Wundermittel Wasserstoff
68	12/2/2019	Handelsblatt	Japan; Weltmacht auf Wasserstoff
69	12/13/2019	FAZ	Nordwesten wird Modellregion für WasserstoffF
70	12/18/2019	Handelsblatt	Ein talentiertes Molekül
71	12/19/2019	FAZ	Im Wasserstoff-Fieber
72	12/23/2019	Handelsblatt	Regierung ringt um Wasserstoffstrategie

73	12/31/2019	Die Welt	Das bezahlbare Wasserstoffauto; Toyota will die Produktion des Mirai mit der neuen Generation deutlich steigern - und den Preis drastisch senken. Das würde den Wettbewerb in der Elektromobilität verändern
74	1/29/2020	Handelsblatt	'Energiepolitik ist der Flaschenhals'
75	1/31/2020	Handelsblatt	31 Maßnahmen für den Weg an die Spitze
76	2/3/2020	Handelsblatt	Frans Timmermans; 'Wir sollten massiv investieren'
77	2/5/2020	Die Welt	Wirtschaft Kompakt; Tarifrunde: IG Metall verzichtet auf Geld-Forderung ++ Blackberry: Aus für Smartphone mit Tasten im August ++ Svenja Schulze: Wasserstoff in erster Linie für die Industrie ++ Mannesmann/Vodafone: Esser: Übernahme war 'großes Unglück' ++ Fraport-Aufsichtsrat: Karlheinz Weimar gibt Vorsitz ab
78	2/7/2020	Handelsblatt	Anja Karliczek und Robert Schlögl; 'Sie können damit Milliarden scheffeln'
79	2/7/2020	Handelsblatt	Ein Molekül macht Karriere
80	2/17/2020	Handelsblatt	Svenja Schulze; 'Wasserstoff ist ohne Alternative'
81	2/24/2020	Handelsblatt	Wasserstoff statt Erdgas
82	2/28/2020	Handelsblatt	Shell plant größtes Wasserstoffprojekt Europas
83	3/3/2020	Handelsblatt	Regierung streitet über Wasserstoff
84	3/7/2020	Die Welt	So wird Wasserstoff grün; Bei der Energiewende setzt die Politik auf Wasserstoff. Doch bislang entsteht bei dessen Produktion schädliches CO2. Zwei Experten erklären, wie sich der Energieträger klimafreundlich herstellen ließe
85	3/7/2020	Die Welt	Kein grünes Gas für Heizungen?; Nationale Wasserstoffstrategie verzichtet aufdas Thema Wärmeerzeugung in Gebäuden
86	3/9/2020	Die Welt	Wirtschaft Kompakt; United-Internet: Neue Allianz für 5G-Ausbau ++ Patienten: Offenheit für digitale Gesundheitsdienste ++ Maschinenbau: Hürden für Wasserstoff abbauen
87	3/17/2020	Handelsblatt	Wasserstoff; Der Regierung fehlt der Plan
88	3/18/2020	FAZ	Wirtschaft plant Wasserstoffnetz
89	3/28/2020	SZ	Wasserstoff marsch!
90	4/2/2020	SZ	Mehr als Wasserdampf
91	4/22/2020	SZ	Schwertransport mit Wasserstoff
92	4/22/2020	Handelsblatt	Brennstoffzelle; Nur eine Nische
93	5/12/2020	FAZ	Gib Stoff
94	5/27/2020	FAZ	Wasserstoff wird ausgebremst
95	5/27/2020	SZ	Explosives Gemisch
96	5/29/2020	Handelsblatt	Energiewende; In der Warteschleife
97	6/5/2020	taz	Skepsis bei der Energie der Zukunft; Das Wirtschaftsministerium bremst die Euphorie über Wasserstoff: Die grüne Energie sei auch langfristig teurer als fossile. Die Regierung will mit 7 Milliarden Euro helfen

98	6/6/2020	SZ	Grün und blau
99	6/6/2020	Die Welt	Neuer Eckpfeiler der deutschen Energiewende; Der Bund plant den Aufbau einer industriellen Wasserstoff-Produktion. Das klimaneutrale Gas soll Transport- und Speichermedium für Öko-Energien werden. Alternativen zum E-Auto können so marktfähig werden
100	6/9/2020	Handelsblatt	Wasserstoffstrategie - Schwere Hypothek
101	6/9/2020	FAZ	Wasserstoff-Einigung
102	6/10/2020	SZ	Klimaneutrale Verheißung
103	6/11/2020	taz	Wasserstoff für die Energiewende; Die Regierung legt ihre lang erwartete Wasserstoffstrategie vor: Mit 9 Milliarden Euro will Deutschland eine Vorreiterrolle einnehmen
104	6/11/2020	Die Welt	Nationale Wasserstoffstrategie ignoriert Autos fast völlig; Im Streit um die beste Antriebsart setzt sich Umweltministerin Schulze durch. Verkehrs- und Wirtschaftsministerium wollten Chance für Brennstoffzellenfahrzeuge
105	6/12/2020	FAZ	Der Wasserstoff bleibt ein Zankapfel
106	6/15/2020	FAZ	EEG-Umlage soll
107	6/15/2020	SZ	Methan und Hitze für den Klimaschutz
108	6/17/2020	SZ	Wasserstoff direkt ab Hof
109	6/19/2020	Handelsblatt	EU-Kommission setzt auch auf blauen Wasserstoff
110	6/22/2020	Handelsblatt	Es gibt keinen bösen Wasserstoff
111	6/23/2020	Handelsblatt	Einen Markt für Wasserstoff schaffen
112	6/25/2020	SZ	Einmal Nordsee und zurück
113	6/26/2020	taz	Wasserstoff soll grün werden; Ein Innovationsbeauftragter soll dafür sorgen, dass die Wasserstoff-Strategie ein Erfolgsmodell wird
114	7/3/2020	FAZ	Energiebranche setzt auf Tausendsassa Wasserstoff
115	7/6/2020	Handelsblatt	Lukrativer Wasserstoff
116	7/8/2020	Handelsblatt	Die Wasserstoff-Welt der Zukunft
117	7/8/2020	Die Welt	Wasserstoff soll Europas schmutzige Industrien sauber machen; Die EU will die Produktion von Stahl und Chemikalien grüner gestalten. Das geht nur mit dem flüchtigen Gas. Die Umsetzung ist schwierig
118	7/9/2020	FAZ	Die EU entdeckt den Wasserstoff
119	7/9/2020	Die Welt	Abgehängt beim Wasserstoff; Volkswagen, BMW und Daimler haben aktuell keine Pkw mit Brennstoffzelle im Programm. Ganz anders große Konkurrenten aus Asien, die diese Technologie deutlich vorantreiben
120	7/9/2020	SZ	Wasserstoff für Europa
121	7/10/2020	FAZ	Trommler für den Wasserstoff
122	7/14/2020	SZ	Grüner Hoffnungsträger
123	7/15/2020	Die Welt	Ablösung des Hochofens; Das Unternehmen Salzgitter treibt den Einsatz von Wasserstoff zur Stahlherstellung voran. Das soll einen wesentlich größeren Effekt fur den Klimaschutz haben als etwa der Ausbau der Elektromobilität

124	7/16/2020	Die Welt	VW klammert sich an das Elektro-Dogma; Der Konzern will zum Marktführer für E-Mobilität werden. An Wasserstoff zu denken, findet Herbert Diess 'nicht sehr sinnvoll'. Der Chef des weltgrößten Automobilzulieferers Bosch widerspricht ihm
125	7/21/2020	Handelsblatt	Anja Karliczek; Ehrgeizig durch die Krise
126	7/25/2020	taz	Ein Mann brennt für Wasserstoff; Heinrich Klingenberg hat bei der Hamburger Hochbahn fast zwei Jahrzehnte lang das emissionsfreie Fahren vorangetrieben. Kürzlich ist er pensioniert worden. Nun kann er sichentspannt ansehen, wie der technologische Wandel Fahrt aufnimmt
127	7/25/2020	taz	Wenn der Wind bläst; Die Raffinerie der H&R Ölwerke Schindler betreibt seit fast drei Jahren eine Elektrolyseanlage zur Herstellung von Wasserstoff für die Energieversorgung der eigenen Produktion
128	7/25/2020	taz	Ein Stoff macht Karriere; Um die Wirtschaft CO2-neutral zu machen, braucht es einen Energieträger, der erneuerbare Energien speichert. Ein Teil der Lösung könnte darin bestehen, aus Wasser Wasserstoff und wieder Wasser zu machen. Die Bundesregierung will das jetzt mit Macht voranbringen. Und Norddeutschland ist vorne mit dabei 43 45
129	7/27/2020	Handelsblatt	BMW tastet sich wieder an Wasserstoff heran
130	7/28/2020	Handelsblatt	Nord Stream 2 soll Wasserstoff liefern
131	8/13/2020	SZ	Salzgitter leidet unter Krise der Autoindustrie
132	8/18/2020	Handelsblatt	Nikola greift die deutschen Lkw-Riesen an
133	8/27/2020	FAZ	Grüne fordern Pflichtquoten für grünen Stahl
134	9/8/2020	SZ	Hoffen auf Inga
135	9/17/2020	Handelsblatt	Daimler auf Diesel-Entzug
136	9/21/2020	Die Welt	Airbus plant mit Wasserstoff; Der Flugzeugbauer setzt bei der Entwicklung neuer Antriebe voll auf eine Strategie - und geht damit eine riskante Wette ein
137	9/21/2020	SZ	Der Traum vom grünen Fliegen
138	9/24/2020	Die Welt	Wohin geht die Reise?; Batterie und Brennstoffzelle könnten sich im Automobilbau ergänzen, meinen Experten. Doch dazu müsste es mehr Investitionen in die Wasserstofftechnologie geben
139	9/25/2020	taz	Heilt Wasserstoff das Klima?; Wasserstoff ist derzeit als angebliches Klimaschutz-Wundermittel in aller Munde. Doch ähnlich wie bei Medikamenten darf zu den Risiken und Nebenwirkungen nicht geschwiegen werden
140	10/1/2020	SZ	Wunderwaffe mit Hindernis
141	10/1/2020	Handelsblatt	Die Neuordnung der globalen Wertschöpfung
142	10/5/2020	Handelsblatt	Überlebensfrage Wasserstoff
143	10/6/2020	taz	Für Stahl ist das eine Perspektive ; heute auf zoom
144	10/6/2020	FAZ	Viessmann setzt auf Wasserstoff
145	10/8/2020	Die Welt	Airbus-Chef sieht in E-Autos eine Mogelpackung; Europas Flugzeugbauer plant CO2-freies Fliegen ab 2035. Bis dahin müsse aber großflächig 'grüner Wasserstoff' zur Verfügung stehen

146	10/8/2020	FAZ	Wir werden nicht alles mit Strom lösen können
147	10/9/2020	Handelsblatt	Der Kampf um das Wasserstoffnetz beginnt
148	10/9/2020	Handelsblatt	Nachgefragt; 'Gewaltiger Schub'
149	10/12/2020	taz	Deutsche Energiewende auf Kosten Afrikas; Mit Wasserkraft aus dem Kongo grünen Wasserstoff für Deutschland herstellen dafür sind hohe Investitionen notwendig. Und eigentlich braucht der Kontinent den Strom selbst
150	10/12/2020	taz	Es reicht gerade für die deutsche Stahlindustrie ; Günter Nooke, Afrikabeauftragter der Kanzlerin, über sein Projekt der Wasserstoffgewinnung im Kongo
151	10/16/2020	Die Welt	Wasserstoff-Ära rückt näher; Ein deutsches Start-up hat kleine Geräte entwickelt, die bald klimaneutralen Brennstoff für alle liefern sollen
152	10/17/2020	SZ	Champagner im Motor
153	10/21/2020	Handelsblatt	Der neue Nikola-Chef wehrt sich gegen Betrugsvorwürfe
154	10/22/2020	Die Welt	'H' wie Hoffnung; Das Element Wasserstoff kann helfen, Energie effizienter zu speichern. Die Idee ist nicht neu, sie erhält aber frischen Rückenwind von Politik und Forschung
155	10/22/2020	Die Welt	Der Treibstoff der Zukunft; Forscher und Unternehmen testen Wasserstoff und Brennstoffzellen, um die Schifffahrt emissionsfrei zu machen. Der Reederverband kritisiert die langsame Umsetzung der Pläne
156	10/28/2020	Die Welt	Ohne E-Fuels drohe das Job-Desaster; Wirtschaft attackiert Umweltministerin
157	10/30/2020	FAZ	Deutsch-französische Wasserstoff-Kooperation
158	10/31/2020	taz	Der Wasserstoff, aus dem die Träume sind; Deutschland will bei sauberer Energie den Markt dominieren, neue Jobs schaffen und die Energiewende voranbringen. Das sieht die Wasserstoffstrategie der Regierung vor. Aber vorher gibt es noch eine Menge Probleme zu lösen
159	10/31/2020	taz	Neue Aufgabe für alte Gasnetze; Wo heute noch Erdgas strömt, soll es in Zukunft der Wasserstoff sein. Ein universeller Energiespeicher beflügelt die Fantasie der Energiewirtschaft nicht zum ersten Mal
160	11/5/2020	Handelsblatt	Bill Gates will Wasserstoffindustrie in Europa aufbauen
161	11/9/2020	Handelsblatt	'Der Brennstoffzelle gehört die Zukunft'
162	11/10/2020	FAZ	Milliardenmarkt Wasserstoff
163	11/10/2020	Die Welt	Elefantenrennen
164	11/10/2020	SZ	Erst grau und blau, dann grün?
165	11/17/2020	Handelsblatt	Die Wasserstoff-Allianz
166	11/24/2020	FAZ	Massive Emissionsminderung in allen Sektoren
167	11/28/2020	SZ	Wasserstoff aufs Gleis
168	12/1/2020	Handelsblatt	Der Weg zu grünem Wasserstoff
169	12/4/2020	Handelsblatt	'Eine Resterampe sind wir definitiv nicht'
170	12/7/2020	Handelsblatt	Wasserstoff aus Marokko mit deutscher Aufbauhilfe
171	12/8/2020	Handelsblatt	Grüner Wasserstoff; 'Voraussichtlich nicht wettbewerbsfähig'

172	12/8/2020	Die Welt	Die grüne Begegnung der nachhaltigen Art; Wasserstoff oder Strom - welche Energie die zukünftige Mobilität dominieren wird, ist umstritten. Argumente gibt es für beide. H2 aber spielt eine wichtige Rolle im Green Deal der Europäischen Union
173	12/8/2020	FAZ	Herkulesaufgabe Wasserstoffimport
174	12/15/2020	SZ	Wasserstoff über den Wolken
175	12/17/2020	Handelsblatt	Wasserstoff aus der Tiefe
176	12/21/2020	Die Welt	'Wir verpassen den Zug nicht noch mal'; RWE-Chef Rolf Martin Schmitz über die Produktion von Wasserstoff und einen Konstruktionsfehler der deutschen Energiewende
177	12/22/2020	SZ	Das Element, das Öl und Kohle ersetzen soll
178	12/28/2020	Handelsblatt	Weltatlas des Wasserstoffs
179	12/29/2020	FAZ	Wasserstoff ins Erdgas mischen

The table shows the identifying number, date, newspaper, and title of each newspaper article included to the analysis.

A.2. Actors

Table A.2 lists all actors, including the number of coded storylines, articles the actor appears in, and different storylines activated by the respective actor. It also shows to which group each actor is assigned to. The discourse is rather concentrated as few actors show significantly more codes than others, and appear in more newspaper articles.

Table A.2: Actor overview

Actor name	Codes	Articles	Different SLs	Group
BMBF	55	26	13	Policymakers
EU Commission	28	11	11	Policymakers
BMWi	27	19	11	Policymakers
BMU	21	12	10	Policymakers
Max Planck institute	20	3	16	Research and think tanks
BUND	19	5	10	NGOs
VW	19	13	3	Transport
FDP	15	6	9	Policymakers
Die Grünen	14	8	10	Policymakers
BDI	11	7	7	Industry
SPD	10	7	6	Policymakers
DUH	9	3	5	NGOs
CDU	8	4	4	Policymakers
Klimaallianz	8	1	8	NGOs

RWE	8	3	6	Electricity
Westenergie	8	1	8	Electricity
Zukunft Erdgas	8	3	7	Gas and heat
BMVI	7	6	2	Policymakers
Dena	7	7	4	Research and think tanks
FNB Gas	7	5	5	Research and think tanks
Fraunhofer ISE	7	4	4	Research and think tanks
Siemens	7	3	5	Industry
Universität Erlangen	7	3	5	Research and think tanks
Amprion	6	3	5	Electricity
BDEW	6	3	5	Electricity
CAR	6	5	2	Research and think tanks
DIHK	6	1	6	Industry
Daimler	6	6	4	Transport
IEA	6	4	5	Research and think tanks
Salzgitter	6	4	4	Industry
Agora Energiewende	5	2	5	Research and think tanks
Bosch	5	4	3	Transport
DWV	5	2	5	Industry
Tennet	5	1	5	Electricity
Toyota	5	3	4	Transport
Uniper	5	4	2	Electricity
VDMA	5	2	4	Industry
Viessmann	5	1	5	Gas and heat
Öko Institut	5	3	4	Research and think tanks
Airbus	4	3	3	Transport
BDH	4	2	4	Gas and heat
DLR	4	3	4	Research and think tanks
DVGW	4	2	4	Gas and heat
EWE	4	2	4	Electricity
GP Joule	4	3	3	Electricity
Hyundai	4	3	3	Transport
Nikola	4	2	4	Transport
Open Grid Europe	4	3	4	Gas and heat
Prognos	4	1	4	Research and think tanks
CEP	3	1	3	Industry
E3G	3	1	3	Research and think tanks
EWI	3	1	3	Research and think tanks
Easac	3	1	3	Research and think tanks

Gazprom	3	1	3	Gas and heat
Greenpeace	3	1	3	NGOs
H2 Mobility	3	2	2	Transport
Hydrogenious Technologies	3	2	3	Industry
Monitoringkommission	3	1	3	Research and think tanks
Senator of Hamburg	3	2	3	Policymakers
Shell Deutschland	3	1	3	Gas and heat
Siemens Energy	3	2	2	Electricity
TH Regensburg	3	2	3	Research and think tanks
Thyssenkrupp	3	3	2	Industry
Total	3	1	3	Gas and heat
VCI	3	2	3	Industry
Vaillant	3	1	3	Gas and heat
Wind2Gas	3	2	2	Industry
Acatech	2	2	2	Research and think tanks
Avacon	2	2	1	Electricity
BMZ	2	1	2	Policymakers
Boston Consulting Group	2	1	2	Research and think tanks
Deutsche Reeder	2	1	2	Transport
EEB	2	1	2	NGOs
ENBW	2	1	2	Electricity
Elring-Klinger	2	1	2	Transport
Energieagentur NRW	2	1	2	Research and think tanks
Equinor	2	1	2	Gas and heat
European Union	2	2	2	European Union
GE Power AG Mannheim	2	1	2	Electricity
GdW	2	1	2	Gas and heat
Get H2 Nukleus	2	1	2	Gas and heat
Greenpeace Energy	2	2	2	Electricity
Horváth & Partners	2	1	2	Research and think tanks
HySolutions	2	1	2	Transport
Hydrogen Council	2	1	2	Industry
InnoEnergy	2	1	2	Industry
LNVG	2	2	2	NGOs
MCC	2	1	2	Research and think tanks
McKinsey	2	2	1	Research and think tanks
Northern Gas Networks	2	1	2	Gas and heat
Plastic Omnium	2	1	2	Transport
RWTH Aachen	2	1	2	Research and think tanks

Ruhr-Universität Bochum	2	1	2	Research and think tanks
Shell	2	2	1	Gas and heat
VDA	2	1	2	Transport
VKU	2	1	2	Gas and heat
World Energy Council	2	2	2	Research and think tanks
Wuppertal Institut	2	1	2	Research and think tanks
Air Liquide	1	1	1	Gas and heat
Arcelor Mittal	1	1	1	Industry
Aurora Energy Research	1	1	1	Research and think tanks
BASF	1	1	1	Industry
BDL	1	1	1	Transport
BeeZero	1	1	1	Transport
Brot für die Welt	1	1	1	NGOs
CAN	1	1	1	NGOs
Creavis	1	1	1	Industry
DNR	1	1	1	NGOs
Die Bahn	1	1	1	Transport
Die Linke	1	1	1	Policymakers
Eon	1	1	1	Electricity
FH Bergisch Gladbach	1	1	1	Research and think tanks
FZ Jülich	1	1	1	Research and think tanks
First Berlin	1	1	1	Research and think tank
Fraunhofer IMWS	1	1	1	Research and think tanks
Fraunhofer ISI	1	1	1	Research and think tanks
Fraunhofer IWU	1	1	1	Research and think tanks
HAW	1	1	1	Research and think tanks
HTKW	1	1	1	Research and think tanks
Hamburger Hochbahn	1	1	1	Transport
Helmholtz-Institut	1	1	1	Research and think tanks
Hyundai Hydrogen Mobility AG	1	1	1	Transport
Hyundai Motors	1	1	1	Transport
IASS	1	1	1	Research and think tanks
IfA	1	1	1	Research and think tanks
Ines	1	1	1	Gas and heat
LEE	1	1	1	NGOs
Mahle	1	1	1	Transport
NGO Kongo	1	1	1	NGOs
NOW	1	1	1	Transport
Nowega	1	1	1	Gas and heat

ÖNZ	1	1	1	NGOs
Roastom	1	1	1	Industry
Schleswig-Holstein Netz AG	1	1	1	Electricity
TU Chemnitz	1	1	1	Research and think tanks
Tesla	1	1	1	Transport
Universität Nürnberg	1	1	1	Research and think tanks
Vonovia	1	1	1	Gas and heat
WWF	1	1	1	NGOs
Total	614	339	424	

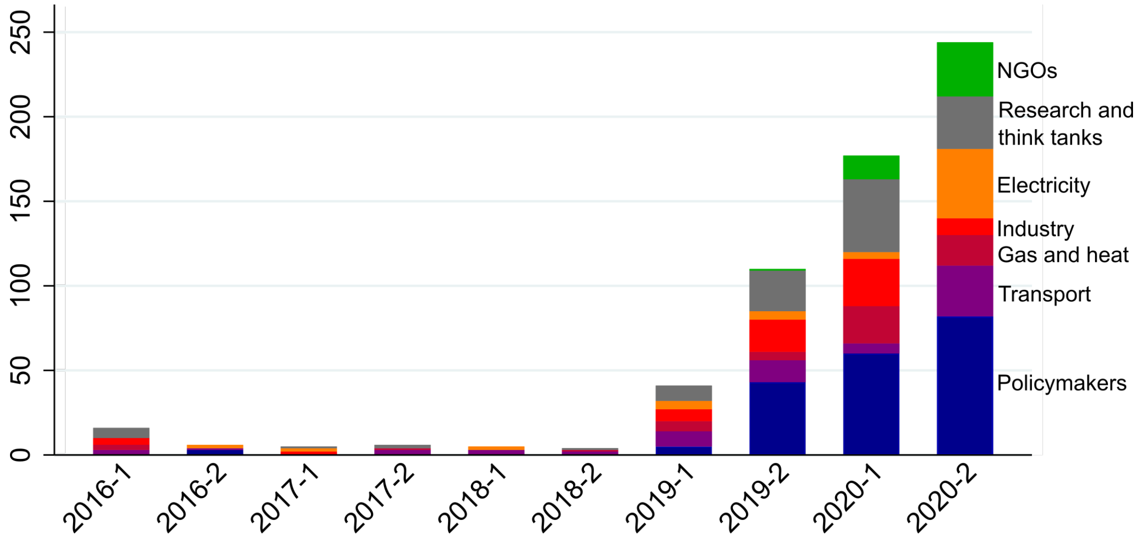
For each actor, the table shows the number of coded storylines (Codes), of appearances in different newspaper articles (Articles), of different coded storylines (Different SLs), and its respective group (Group).

A.3. Temporal development of discourse

Figure A.1 shows the participation of actor groups in the discourse over time. Before 2019, storylines that characterize the ongoing hydrogen discourse were scant. Newspaper articles covering hydrogen usually focused on fuel cell cars, or occasionally on power-to-X. The ongoing hydrogen discourse started in 2019. The start coincides with the declaration by the German chancellor Angela Merkel that net-zero emissions by 2050 would be the new climate target. The number of of coded storylines tripled between the first and the second half of 2019. In 2019, the discourse was overall dominated by policymakers, research institutes and think tanks, and industry actors. In 2020, the absolute number of codes for these groups remained stable, but additional actor groups entered the discourse: the gas and heat sector became increasingly visible in the first half of 2020, while NGOs, the electricity and transport sector, and the EU joined in the second half.

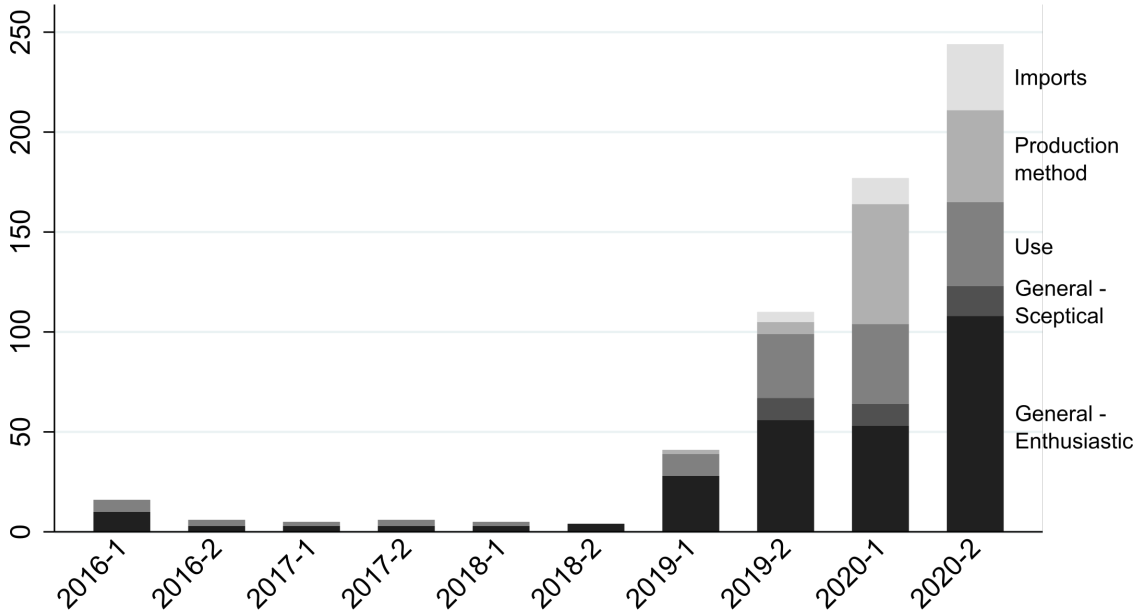
Figure A.2 shows how the three conflicts, as well as skeptical and enthusiastic storylines in the general discourse on hydrogen evolved over time. In 2019, the discourse is dominated by enthusiastic storylines and the conflict about its use. The conflict about production methods becomes more important in early 2020, while discussion about imports begin only in late 2020. skeptical storylines appear in late 2019, but overall remain an exception.

Figure A.1: Attention actors



The figure shows the frequency of coded storylines between 2016 and 2020 in half year bins stacked by actor groups.

Figure A.2: Attention storylines



Notes: The figure shows the frequency of coded storylines between 2016 and 2020 in half year bins stacked by storylines.

Chapter 6

Synthesis and Discussion

Limiting the global average temperature increase to well below 2°C, and ideally to 1.5°C above pre-industrial levels, needs a rapid reduction of carbon emission, and more low-carbon innovation. Understanding which climate mitigation policies would effectively reduce carbon emissions, while at the same time triggering low-carbon innovation, is hence key. However, political economy factors may affect whether such climate policies can be implemented. The political economy around energy transitions thus needs to be understood and addressed.

This dissertation therefore attempts to understand what characterizes effective climate mitigation policies, why they are not implemented at sufficient pace and stringency, and how to eventually address and overcome hindering political economy factors. It shows how cap-and-trade systems can be reformed to effectively trigger low-carbon investment, which political economy obstacles lead to a continued deployment of coal-fired power plants, and how political economy factors shape the discourse around the emerging hydrogen economy.

The first section of this chapter synthesizes the findings of the Chapters 2-5 and derives broader conclusions. The second section more deeply discusses selected aspects that deserve special attention, as outlined in the following. When considering all findings in conjunction, it becomes evident that climate policies need to be both effective and politically feasible. The first part elaborates design options of effective climate mitigation policies, and strategies supporting their implementation. Building new coal-fired power plants meets several societal objectives of emerging economies. The second part outlines whether, and how, instead renewable energies could meet these objectives. From this dissertation, two challenges related to the political economy of i) emission reductions and ii) low-carbon innovations emerge. The third part addresses the first challenge and discusses specific strategies to overcome resistance by fossil fuel incumbents against ambitious climate mitigation policies. The last part addresses the second challenge by discussing implications for the discourse arising from the upcoming transitions to net-zero with a focus on hydrogen.

6.1 Synthesis

Chapter 2-5 of this dissertation investigate different aspects of climate policy, from instrument design, to political factors affecting emission reductions, and low-carbon innovations. The following main findings emerge from each respective chapter. Chapter 2 shows that price floors above current expectations in emissions trading systems lead to higher low-carbon investments, and abolished fossil investments. Chapter 3 finds that economic growth, cheap energy prices, and energy system stability are the most important political economy factors that lead to a continued deployment of coal-fired power plants in major coal countries, while environmental factors are less relevant. Chapter 4 reveals that main objectives guiding policies in the Indian power sector are to provide sufficient and affordable electricity and to promote the domestic energy industry, while policies are also highly affected by personal interests. Chapter 5 shows that the emerging German hydrogen discourse is characterized by a high agreement about the general goal to establish a hydrogen economy, but that there are conflicts around the use, production method, and imports of hydrogen, which are partially guided by special interests.

6.1.1 Price floors to ensure effective emissions trading systems

Chapter 2 surveys managers from German energy companies about the impact of different carbon price floor trajectories in the EU ETS on their investment decisions. The online survey results are analyzed using an ordered probit model that distinguishes between different types of companies and the uncertainty of expected carbon prices. The analysis finds that a high price floor trajectory in the EU ETS above expected prices would lead to higher low-carbon investment, whereas a lower trajectory, that only serves as an insurance against low prices, would leave investment decisions largely unchanged. Especially green electricity companies would increase their investment level compared to the status quo, while energy-intensive companies, with thus far compensated carbon costs, would decrease their fossil investment.

The findings add to both the academic and political debate about the effectiveness of carbon prices in fostering investment to low-carbon technologies. Determining the effectiveness of carbon pricing policies using ex-post analyses is challenging (see Section 1.2.2), and previous ex-post studies show different magnitudes in terms of emission reductions and innovation activities. Referring to a set of studies that show rather small impacts of carbon prices on firms, a minority of scholars question the general adequacy of carbon pricing as a climate policy instrument to induce emission reductions and low-carbon innovation. However, different levels of impact of carbon pricing policies can be generally explained via methodological differences in the analyses, different analysis scopes (such as country or firm level), and ultimately differences in the policy design of the carbon pricing scheme under research. Within the last, the price level and potential exemptions are important factors for the effectiveness. Most implemented carbon pricing schemes suffer from low price levels (see Section 1.2.3), while the EU ETS only since very recently builds a noticeable exception. However, ex-post analyses are bound to analyze the impact of actually implemented prices, while the theoretical argument that higher prices will also lead to higher effectiveness, has lower political leverage. Having empirical insights on the effectiveness of also higher carbon prices would thus be highly relevant to justify and sustain a continued political support for increasing carbon prices.

The findings of Chapter 2 are an important contribution to this debate. The approach of eliciting decisions of managers ex-ante is rather unconventional in economics, but builds a valuable complement to insights from ex-post studies. The chapter shows both, the change in the level of investment, but also how portfolios of different company types would change in response to a price floor. The findings may motivate policymakers to further reform existing cap-and-trade schemes by adding price floors, while future carbon pricing schemes could include this design element from the very beginning. Policymakers can furthermore be reassured that ambitious carbon prices may indeed lead to the aspired outcomes of emission reductions and innovation.

6.1.2 Global patterns in the political economy of coal

Chapter 3 surveys energy experts from eight major coal countries on the political economy of coal deployment. The online questionnaire distinguishes between contextual factors, objectives, actors, and explicitly elicits corporate political strategies and arguments of pro-coal actors. The results show that three main objectives, namely economic growth, energy system stability, and low energy prices are consistently the most relevant factors across the countries, while environmental factors are less relevant. Moreover, the energy ministry and the head of state are considered as the most important political actors, and utilities and mining companies as the most important economic actors. Societal actors are least important. The power sector influence and the power market structure are the most important contextual factors.

Considering all these findings in conjunction allows to draw several policy implications. The findings make clear that policymakers are the most important actors for determining future coal deployment, and shaping the pace and stringency of upcoming coal phase-outs. Yet, the chapter also shows that the political feasibility of coal policies is affected by the above mentioned societal objectives and contextual factors. Aligning renewable energies with societal objectives is one important way forward, while overcoming resistance of incumbent actors from the power sector is another (see Section 6.2.3 and 6.2.2 for more extensive discussions on both aspects).

The chapter also entails implications for international policymakers from non-coal countries: They could support domestic policymakers that envisage coal phase-outs, as international support may legitimize enacting policies that hinder further coal deployment. The COPs have thus far been the most important international policy arena for coal related negotiations. The COP 26 in Glasgow during in November 2021 has for the first time led to the acknowledgement of a *coal phase-down* of unabated coal power usage, although the initial formulation of aspiring a *coal phase-out* was blocked last minute by China and India. International negotiators in subsequent COPs could try to further address domestic factors hindering policymakers from further commitments, for example by promising financial support to workers in affected regions, or reducing financing costs of renewables by de-risking investments. Another increasingly discussed approach is the establishment of climate clubs, i.e. groups of countries cooperating on climate change policy. Climate clubs could provide an important extension to COPs, as a membership would entail additional incentives for policymakers in coal-dependent countries to phase-out coal.

6.1.3 Coal politics in emerging economies: Insights from India

Chapter 4 investigates the political economy of coal in India based on semi-structured interviews with Indian energy experts. The interviews were systematically analyzed and the results structured along the four most important objectives driving India's coal investment decisions. First, it shows that ensuring a sufficient supply of energy was a main factor shaping India's coal investments in the last decades. To meet this objective, the Indian government liberalized the power market, which resulted in large private coal investments. Second, ongoing public coal investments aim to ensure the availability of electricity in the long-term. Third, maintaining regional jobs and safeguarding local vested interests in the coal sector are important factors hindering a transition away from coal. The fourth, but less relevant objective, was to reduce air pollution by introducing pollution regulations in response to demands by a rising middle class. However, these regulations remained largely ineffective, as successful lobbying led to postponed or less ambitious regulations.

These in-depth insights into the energy politics of India as a major coal-producing and consuming emerging economy complement the comparative analysis of Chapter 3.

The stability of the energy supply in the short and long term stand out as the single most important objective in India's energy sector, which is similar in other emerging economies investing in coal. In Section 6.2.2, I more extensively discuss the implications of meeting the objectives of energy supply and economic growth in general, and whether these objectives may be also be met by renewable energies. Considering regional implications of coal is the second most important objective that similarly applies to other emerging economies engaging in coal mining. A large number of formally and informally employed workers depend on coal. This outcome suggests that more deeply engaging with local factors in an emerging economy context may become important when thinking about eventual coal phase-out policies. This finding is also in line with evidence from previous coal transitions in industrialized countries, where regional unemployment has also been very important. Developing transition schemes that address the regional context, while being affordable also for emerging economies, will pose a major challenge in the next decades.

6.1.4 Struggles around the discourse of hydrogen

Chapter 5 analyzes the German hydrogen discourse based on newspaper articles and interprets the findings based on a new conceptual framework for multi-sector transitions. The chapter finds that a broad variety of actors overall agrees that establishing a hydrogen economy would be beneficial. However, it also identifies three emerging lines of conflict over the the envisaged use of hydrogen, its preferred production method, and the desirability of imports. A discourse network analysis shows that actors from environmental NGOs advocate using exclusively green hydrogen for a limited number of uses, while raising concerns about specific aspects of hydrogen imports. In contrast, especially actors from the gas and heat sector support the production of also non-green hydrogen, and using hydrogen more widely across multiple sectors and for multiple uses. Stances of other actors on risks and opportunities of hydrogen imports are heterogeneous. The conceptual framework helps interpreting sectoral differences of adopted storylines by highlighting the context of sectoral transitions, the availability of low-carbon technologies, and business interests of actors arising from hydrogen- and electricity-based technologies and associated infrastructures.

The competing use of low-carbon hydrogen and renewable electricity is part of larger discussions about how to best achieve the net-zero goal in the upcoming decades. The early German discourse outlines major conflicts that will gain further prominence in the next years. These conflicts also affect incumbent actors from a broad variety of sectors have much to lose, or to win, respectively. Uncertainty about the optimal technology choice render decision-making for policymakers about which technologies to support particularly challenging. The findings of this chapter may increase the awareness of policymakers about potential underlying interests and motivations from industry incumbents, and thus allow to better assess their advice. Similar discourses are likely to emerge in other countries across the globe that aspire to achieve net-zero emissions using hydrogen. The generic conceptual framework may build a suitable starting point to improve the understanding of transitions with two or more low-carbon options spanning across multiple sectors at once, and how this may affect, and increase, the complexity of discourses.

6.2 Discussion and future challenges

Achieving the net-zero goal will require the implementation of climate policies initiating a rapid coal phase-out, renewable deployment and low-carbon innovations. The implementation of such policies requires considering political economy aspects, which particularly includes resistance by fossil fuel incumbents. Special challenges arises for emerging economies, which face the trade-off between emission reductions and economic growth.

The next parts describe how to develop effective, just and feasible climate policies (6.2.1), whether and how renewable energies may satisfy similar societal objectives as coal power has done in the past (6.2.2), and how to overcome challenges arising due to the political economy of emission reductions (6.2.3), and low-carbon innovation with a focus on hydrogen (6.2.4).

6.2.1 Developing effective, just and feasible climate policies

Chapter 2 shows that a carbon price floor above ex-ante expectations leads to increased low-carbon, and abolished fossil investment. While price floors as a design component of cap-and-trade systems would increase their effectiveness, it remains unanswered, whether cap-and-trade systems are by themselves sufficient policy instruments to rapidly trigger low-carbon innovations, and, under which conditions adopting effective climate policies would become politically feasible. The following paragraphs discuss how carbon prices could be complemented by additional climate policies to ensure a sufficiently rapid and high low-carbon investment. Subsequently, I argue that targeted revenue recycling schemes, and an enhanced communication may increase the political feasibility of effective climate policies.

Price floors in cap-and-trade systems could reduce uncertainty in price expectations by inhibiting price drops, increasing the price level, raising the overall credibility of climate policies, mitigating myopic behaviour of companies and investors, and partially addressing dynamic inefficiencies (see Section 1.2.5 and Chapter 2). However, the time-inconsistency problem (Kydland and Prescott, 1977) remains a general challenge for any forward-looking policy, as policymakers will inevitably face pressure or incentives to eventually adjust policies to maintain their power. This may result in entirely, or partially abolished climate policies, for example in order to lower the financial burden of specific interest groups. The level of power by future policymakers to adjust policies affects the policy credibility, and thus the level of uncertainty faced by market participants taking investments decisions. However, commitment devices that complicate policy changes and thus constrain the option space of policymakers in the future can affect the credibility of climate policies (Brunner et al., 2012). Practical proposals comprise specific types of legislation, such as altering the constitution rather than only adopting a statutory law, establishing an independent energy agency in analogy to central banks in the financial sector (Helm et al., 2003), or securitization, such as creating contractual agreements with private actors that would be costly to breach (Brunner et al., 2012). Implementing such additional commitment devices along with carbon pricing policies thus appears as an important extension.

Different types of technology subsidies could complement carbon prices. Companies having business models based on fossil fuels are directly affected by carbon prices. Their current and expected costs directly increase, with the consequence, that investing into emission abatement leads to foreseeable cost reductions. Yet, carbon prices only indirectly affect companies that exclusively focus on innovative low-carbon technologies. For these companies, carbon prices provide only a potential competitive advantage against competitors relying on fossil fuels, with financial returns being inherently uncertain and thus risky, unless the time-inconsistency problem would be solved entirely. This risk may inhibit low-carbon innovation at the scale necessary to rapidly transition towards net-zero economies. Different forms of technology subsidies complementing carbon prices could reduce this risk. For example, feed-in-tariffs above generation costs, or competitive auctions combined with long-term power purchase agreements, supported the deployment of renewable energies in various countries, leading to de-risked and thus increased renewable energy investment, and significant innovation and costs reductions (IRENA et al., 2018).

Comparable policy instruments could trigger additional low-carbon innovation to achieve the net-zero emissions goal (Chiappinelli et al., 2020). Carbon Contracts for Differences (CCFDs) are one discussed policy instrument option for energy-intensive industries in Germany (Neuhoff et al., 2018; BMWi, 2022). CCFDs subsidize the low-carbon production of goods up the level required to be competitive against production based on fossil fuels. The subsidy level per produced unit thereby equals the difference between low-carbon production costs, and production costs using fossil fuels plus the current carbon price. Risks related to low, or fluctuating carbon prices, are thereby entirely removed from the regulated company, and taken up by the regulator. A potential information asymmetry between the regulator and the regulated company about the production costs could be offset by setting benchmark prices at the level of the best available technology, or by tender, while revenues from carbon prices could be used to finance the policy (Chiappinelli et al., 2020). Such contractually guaranteed payments would also serve as a commitment device.

A pre-requirement for the adoption of effective climate policies is their political feasibility, while normative considerations require that climate policies do not overly burden vulnerable groups. Thinking about climate policy design should thus consider distributional impacts and political economy factors. Based on the AOC framework (Jakob et al., 2020), it can be argued that policy proposals are feasible if they satisfy the objectives of political actors and highly influential societal actors. In other words, policymakers that are formally entitled to adopt a policy proposal, either directly, or by voting for its adoption in parliament, need to consider adopting the policy proposal as in their best interest. Relevant objectives comprise, among others, power considerations, such as maintaining individual and party power, and normative considerations, such as a favorable impact on the population, without overly burdening vulnerable groups. In this view, a politically feasible policy proposal at once aligns multiple important objectives. Other scholars find that specific factors affecting the political feasibility may differ by the stage of the policy cycle (Webber, 1986).

Targeted revenue recycling schemes considering the political economy are one specific option to enable the adoption of carbon pricing policies (Klenert et al., 2018). Carbon pricing alters the costs of goods, and thus has distributional impacts on firms and households. Revenues from carbon pricing can be targeted to alter distributional impacts in general, and specifically to protect vulnerable groups (Maestre-Andrés et al., 2019). Targeted revenues can also compensate groups that lose from climate policies (see part 6.2.3 for more discussion on overcoming resistance by incumbent companies), or reduce the investment risk of low-carbon innovations (Carl and Fedor, 2016). However, although carbon pricing in combination with revenue recycling allows to address various concerns, it is still often very unpopular (Mildenberger et al., 2022). For example, the Australian carbon tax has even been repealed a few years after implementation due to public protests (Rahman, 2013; Sajeewani et al., 2015), and so have various fossil fuel subsidy reforms (Clements et al., 2013; Soile and Mu, 2015; Lockwood, 2015; Dorband et al., 2017). Support for carbon pricing policies may increase by salient progressive distributional impacts based on lump-sum transfers that are accompanied by a suitable communication strategy (Carattini et al., 2017).

The communication of climate policies and the public perception of climate policies are thus pivotal (Capstick et al., 2015; Kahan, 2015; Atansah et al., 2017). One pre-condition for the public support of climate policies is a perceived scientific consensus that global warming is a real threat, along with it being caused by humans, serious, and solvable (Ding et al., 2011). Conservative think tanks have in the past systematically raised doubts about the existence of climate change (Oreskes and Conway, 2010), while the debate more recently shifted towards promoting narratives that delay the implementation of effective climate policies (Lamb et al., 2020). Winning hegemony in a discourse is extremely challenging. It nevertheless appears to be important to further engage with the question how climate communication can be altered to gain broader support, especially in the context of an increasing relevance of social media. In summary, this discussion provides several avenues on how to design effective mixes of climate mitigation policies, and reflects about factors affecting the political feasibility of climate policies in general.

6.2.2 Renewable energies for emerging economies

Chapter 3 shows that three major objectives, namely economic growth, low energy prices, and a reliable energy supply, contribute to a sustained deployment of coal-fired power plants in emerging economies. Environmental concerns only play a minor role. Under the simplifying assumption that policymakers are ultimately guided by specific societal objectives when taking energy-related political decisions, there emerge two general options how renewable deployment could become more desirable than coal. First, environmental objectives could become at least as important as energy and growth related objectives. Second, when assuming that the ranking of societal objectives remains unchanged, it would require that renewable energies satisfy the same objectives as coal does currently.

The first option would imply that the ranking of societal objectives adjusts towards an increased environmental awareness. Steering such a process, if overall within the power of policymakers, would be challenging, and likely a long-term endeavour without a guarantee of success. This particularly applies for emerging economies, where the strive for economic growth, being associated with higher well-being and prosperity, roots fundamentally in the fact that still many people suffer from poverty. In this context, economic growth and energy access as primary societal objectives also appear desirable. Given economic growth being a desirable objective, and the adjustment of objectives possibly beyond control, it appears more promising to focus more on the second option. In the following, I therefore elaborate potentials and obstacles of renewables in meeting societal objectives that have thus far been met by coal power, how meeting these objectives could be facilitated, and which barriers may remain in the long-run.

To understand whether and how renewable energies could replace coal in fulfilling the objective of economic growth, it requires understanding why coal fosters economic growth in the first place. Chapter 1.3 discussed the historic connection between coal and growth in the industrial revolution of Western economies, and how this may still serve as a role model for emerging economies.

There are two different growth channels of coal. First, generating electricity via coal enables and facilitates the industrial development of the entire country. That electricity induces growth requires meeting both other objectives, namely that electricity shall be cheap and reliable. Second, coal directly fosters regional growth. To use coal, it requires a large associated infrastructure that, depending on the country, may comprise mining, transport, and power generation facilities. The proximity to coal mines, moreover, benefits heavy industries that use coal directly, as this reduces potentially high transport costs. Such regional impacts of coal have in the past been a decisive political economy factor in coal phase-out discourses. To understand whether, or how, renewables can equally well address both growth channels, the following paragraphs discuss differences between the generation of renewable and coal electricity on both growth channels.

The relationship between electricity generation and economic growth is generally well-established. However, costs and quality of electricity are influencing factors. Electricity is a homogeneous and heterogeneous good at once, leading to different economic values of electricity generated by fossil, or variable renewable sources (Hirth et al., 2016). This practically implies a differing quality of electricity in terms of available capacity over time, or overall capacity constraints. Differences are particularly pronounced for developing countries, where the selection between off-grid and on-grid power supply may affect the quality of electricity, resulting energy services, and ultimately the development outcomes (Jeuland et al., 2020). Energy systems with high shares of fluctuating renewables are more complex to operate. Despite tremendous price decreases of generation costs for renewables in the last decades (Kavlak et al., 2018; Steffen et al., 2020; IRENA, 2021), and additional expected decreases in the future (Wiser et al., 2016; Creutzig et al., 2017; Wiser et al., 2021; Victoria et al., 2021; Luderer et al., 2021), integration costs are expected to increase, and thus gain in relevance with higher shares of fluctuating renewables (Ueckerdt et al., 2013; Hirth et al., 2015; Wiser et al., 2017). Integration costs comprise different components covering transmission and storage infrastructure required to balance fluctuating renewable electricity (Ueckerdt et al., 2013; Gorman et al., 2019). However, estimating these costs is challenging due to thus far scant knowledge and a high dependency on the specific context (Wiser et al., 2017; Gorman et al., 2019). Another often overlooked cost component arise from operation and maintenance (Steffen et al., 2020).[5] Overall, there is a risk that renewable electricity may be of lower quality, and it seems likely that costs of power systems with high renewable shares may eventually increase.

Moreover, costs of renewable power systems in emerging economies will possibly be higher than those in industrialized economies. Thus far, financing costs for the deployment of renewables were larger in emerging economies than in industrialized countries due to higher risks, such as potential construction delays, defaulting payments of customers, or the expropriation of the facility (Schmidt, 2014; Hirth and Steckel, 2016; Steffen, 2020). Such higher investment costs in developing countries may even exceed initial cost advantages arising from a stronger solar radiation (Ondraczek et al., 2015). There is no reason to assume why systematically higher financing costs for emerging economies should eventually diminish, especially when considering that power systems with high renewable shares are more complex, which may further increase financing risks. Coal power may thus remain the cheaper power generation option in the long-run when neglecting external costs, at least for some emerging economies.

Doubts about the general compatibility of intermittent renewables with an industrialized economy, as they would be less reliable, pose another challenge as outlined by several interviews with Indian energy experts conducted for Chapter 4. However, despite several challenges, there are no fundamental technical reasons that prevent large capacities of renewable electricity to be available and reliable (Perez-Arriaga and Batlle, 2012; Ford and Hardy, 2020). Industrialized countries are on their way to practically demonstrate the technological and economical feasibility of integrating high shares of renewables to their power systems. The resulting net-zero energy systems will combine renewable energy and storage technology, efficiency improvements, demand side adjustments, and novel technologies and regulatory designs (Davis et al., 2018). However, these fundamental transitions towards low-carbon energy systems may need several decades (Deutch, 2020; DeAngelo et al., 2021). Postponing such transitions for emerging economies risks locking-in a fast growing fossil energy infrastructure. It is thus essential that industrialized countries as soon as possible show that affordable and reliable power systems based on renewable electricity are feasible. It thus requires successful demonstration projects of industrialized countries, while at the same time transforming their overall energy systems. A rapid energy transition of industrialized countries showing that renewable energies and industrial production are compatible with each other may thus motivate emerging economies to adopt similar strategies.

Prices of power generation technologies are affected by the politically shaped design of power markets. In the last decades, policymakers have tried to ensure the profitability of renewable electricity by introducing feed-in-tariffs and auction systems, thereby setting high incentives for investors for the deployment of renewables and low-carbon innovation (IRENA et al., 2018). Carbon prices can in turn significantly increase generation costs for electricity based on coal and natural gas. Combining both approaches could effectively set incentives for the deployment of renewables. When embedded to a wider and credible decarbonization strategy, this could potentially even decrease existing markups on investment costs. However, such policies would ultimately increase the short-term costs for power generation,

[5] Operation and maintenance costs may amount up to 25%, but bear the potential to decrease due to continued learning (Steffen et al., 2020).

and thus hamper economic growth of emerging economies. Making renewables the cheapest option for power generation may require international financial support. The international community should therefore consider to introduce transfer schemes, or reduce financing costs, for example, by providing guarantees to investors (Griffith-Jones et al., 2012; Gabriel, 2016). The IEA recommends a plethora of measures to leverage energy finance in emerging and developing economies, such as increasing the mandate of international financial institutions, mobilizing more private capital, while adjusting domestic financing conditions in favor of sustainable investments (IEA, 2021). Having discussed the impact of prices and intermittency of renewable electricity in the emerging economy context, I now discuss whether renewable deployment could offset adverse regional impacts induced by coal-phase outs by creating new job opportunities and regional economic growth.

That the deployment of renewables will lead to regional jobs and growth in previous coal regions is unlikely, although most studies point towards a long-term increase of jobs in the power sector on aggregate (Almutairi et al., 2018; Ram et al., 2020; Malik et al., 2021; Pai et al., 2021). First, as renewable energy equipment is traded internationally, it is not given that the production of renewable energy equipment takes place in thus far coal dependent countries. For example, China and Malaysia are the main producers of solar equipment for India, that has a comparably small PV manufacturing sector. Second, even if thus far coal dependent countries were to become producers of renewable energy equipment, they would need to ensure that the renewable energy production facilities are located close to former coal mines. Whether these locations are optimal choices cannot be taken for granted, while deploying renewable power plants, another potential employment source, depends on geographical conditions. It is moreover unclear whether retraining coal workers to become renewable energy manufacturers would be feasible (Pai et al., 2020; Carley and Konisky, 2020). Given that not all former coal-dependent countries can become internationally competitive producers of renewable energy equipment, it is likely that former coal mining regions in these countries would *ceteris paribus* face higher unemployment. Apart from the geographical mismatch between coal and renewables, it would finally be unclear, whether regional spillover effects induced by renewables would equal those of coal in relation to the installed capacity. Renewables do not require extracting resources and need less associated infrastructure than coal, which requires ports, railways or roads. Moreover, they may attract energy-intensive industries to a lesser extent, as renewables cannot replace chemical properties of coal that, for example, were needed for the production of steel. In summary, these arguments suggest overall less regional indirect and induced jobs, and spillover effects from renewables compared to coal.

Offsetting adverse regional impacts and ensuring sustained regional growth when phasing-out coal requires well-designed energy policies that are tailored to the emerging economy context. Learning from previous coal transitions that lead to regional transformations appears a reasonable starting point. For example, in Germany, an expert commission comprising various stakeholders, recommended to phase-out coal until 2038, and proposed several measures to accompany this process (BMWi, 2019). The German *coal commision* in 2019 proposed to guide the regional structural change by funding affected regions with roughly EUR 40 bn to build research institutes, industrial facilities, and governmental agencies, to provide long-term job perspectives for affected people. Owners of early retired coal power plants were compensated with more than EUR 4 bn. However, this strategy may neither be generally desirable, nor transferable to the context of emerging economies. First of all, by extensively addressing entire regions and compensating coal companies, the German coal transition is extremely costly. One option to reduce costs would be to tailor public funds closer to actually affected workers. Second, emerging economies could be confronted with the administrative challenge of successfully targeting particularly vulnerable groups when considering partially high shares of informal employment in coal mining sectors of emerging economies (Lahiri-Dutt, 2018). Funding by the international community could further ease the financial burden faced by emerging economies that strive for phasing-out coal. While options for efficient climate policies have been studied extensively, more research is needed about how to enable just transitions of coal regions in emerging economies.

In this section, I have discussed the challenges of meeting the objective of economic growth using renewable energy technologies instead of coal power. The section provides potential pathways for international and domestic policymakers that outline how they can sustain economic growth and mitigate regional impacts of coal-phase outs. Solutions comprise providing financial incentives by industrialized economies for the deployment of renewable energies, internationally demonstrating the technical feasibility of renewable power systems, and to support regional transitions schemes.

6.2.3 Addressing "Challenge one": Resistance of fossil incumbents

Overcoming the resistance of fossil fuel incumbents poses a major political economy obstacle for adopting ambitious climate mitigation policies, such as high carbon prices (see Section 1.3). This part first reviews insights from previous coal transitions, and then describes strategies to successfully overcome resistance agsinst the implementation of ambitious climate policies.

Several lessons can be learned from theory and historic energy and coal transitions. Policies accompanying coal transitions ideally balance a variety of different factors at once, covering ethical aspects, economic efficiency, and political factors that comprise targeting different beneficiaries (Spencer et al., 2018). Important insights can be extracted from an extensive review of studies on previous coal transitions that compiles evidence about drivers and barriers, different types of outcomes, and previously applied policy instruments (Diluiso et al., 2021). The authors differ between *transition policies* that initiate coal transitions, and *management policies* that address environmental, economic, or social impacts of ongoing transitions. In the past, the most important transition policy was air quality regulation, whereas economic instruments, such as carbon prices, have been only used more recently. Management policies addressing economic and social aspects focused on investment strategies and financial aid or compensatory measures.

Yet, whether there is sufficient support for policymakers to enact such policies may depend on various influencing factors. The adoption of national climate policies can be constrained by the exposure to fossil fuel extraction activities, a dependency on coal, lacking democratic norms, corruption, low public awareness of climate change, and low levels of social trust (Lamb and Minx, 2020). Others highlight the role of institutional quality, and trust in people and political institutions for the adoption of different types of climate policies (Davidovic and Harring, 2020), or discuss how national political institutions, international aspects, and bureaucratic structures affect the build-up of climate institutions (Dubash, 2021). An analysis of preconditions for implementing carbon pricing schemes covering social, political, and economic aspects shows that fossil fuel consumption is a main barrier to carbon pricing, while well-governed institutions and the public opinion are major drivers for the implementation (Levi et al., 2020). Helm (2010) argues that governments have failed in implementing effective climate policies due to successful rent-seeking and regulatory capture leading to higher mitigation costs than commonly assumed. The findings overall show that domestic political economy factors may decisively influence the capability of policymakers to implement phase-out policies.

Support for enacting ambitious climate policies may thus need to be established first. Scholars have therefore developed the strategies of creating winning coalitions and policy sequencing (Meckling et al., 2015, 2017; Pahle et al., 2018). These follow the overall idea, to support the establishment of green industries that afterwards provide the necessary political support for more effective and comprehensive climate policies. Meckling et al. (2015) propose to first implement green industrial policies that target specific regions, sectors, or technologies, and emphasize that such industrial policies need to impose significant shifts, in contrast to only incremental improvements. Following this approach would ideally create a positive feedback loop of creating increasingly powerful coalitions of actors in green industries, that generate support for more effective climate policies, which then increase the power of coalitions even more. They recommend that sequencing of climate policies should be done more strategically, and explicitly highlight that such an approach may support the introduction of high and thus effective carbon prices.

Targeted compensation schemes are another important tool for policymakers to overcome resistance by fossil fuel incumbents. Compensation schemes in general can be directed either at regions, workers, or coal companies, and comprise a variety of specific policy instruments that aim for direct compensation, or support in structural adjustment (Spencer et al., 2018; Green and Gambhir, 2020; Diluiso et al., 2021). A panel analysis of the political economy of carbon pricing, covering policy introduction and stringency, shows that compensating or weakening incumbents are important for a successful implementation (Dolphin et al., 2019). There are several options to compensate incumbents that will lose from a transition. For example, grandfathering generally describes exemptions from regulations, or restrictions for actors that would be affected otherwise (Trebilcock, 2014). Adjusting the timing of policy implementation by postponing the implementation of the policy, or implementing the policy only gradually, are complementary options. For example, emission permits in the EU ETS were initially distributed completely for free with an allocation based on historical emissions, putting no immediate costs to compliance companies. European policymakers have later reduced these grandfathered permits and included them to auctioning systems.

6.2.4 Addressing "Challenge two": Struggle over hydrogen deployment

The innovation of low-carbon technology to achieve net-zero emissions faces novel challenges, arising from a heterogeneous set of potential losers obstructing transitions, and uncertainty of policymakers about optimal transition pathways. While interests of incumbents relying on fossil fuels were equally present during previous energy transitions, an increased complexity and uncertainty evolve from implications of the net-zero goal, as illustrated for the case of hydrogen (see Section 1.3.4). Due to the novelty of the topic, extant literature is scant. In the following, I discuss potential discursive strategies of incumbent actors that risk losing from net-zero transitions, comment on how some of these general strategies are already visible in the case of hydrogen, and discuss implications for policymakers.

Fossil fuel incumbents under pressure to decarbonize their businesses may try to influence climate policy making. Resistance of incumbent actors towards sustainability transitions has been conceptualized (Geels, 2014; Smink et al., 2015) and observed in multiple empirical settings, especially in the power sector (Geels et al., 2016; Leipprand and Flachsland, 2018). However, novel elements around the net-zero emissions goal distinguish ongoing and upcoming transitions from previous ones. These transitions may span across multiple sectors, affect multiple technologies, provide multiple potentially co-existing solutions, and thus lead to more complex positions of actors. Analyzing discourses around potential solutions are one way infer the positions of involved actors. The position of opponents in the climate change discourse has in many countries recently shifted from denying the problem of climate change (Farrell et al., 2019), towards accepting the overall goal to achieve net-zero emissions. However, despite acknowledging the net-zero goal, adversely affected incumbents may still try to i) delay the transition within their sector, or ii) promote potentially sub-optimal transition pathways that align with their business interests. Once an (unfavorable) transition appears inevitable, they may furthermore change their strategy and iii) try to obtain public funding via subsidies, or compensation for lost revenues.

There are multiple strategies incumbents may choose to delay or influence transitions in their sector, including the participation in expert and public discourses. Applying delay strategies as categorized by Lamb et al. (2020),[6] incumbents may try to i) *redirect responsibility*, for example by suggesting that other sectors having higher emissions would need to transition more rapidly, ii) *push for non-transformative solutions* that only require incremental adjustments of the existing infrastructure or are characterized by technological optimism, or iii) *emphasize the downsides* of climate policies, such as job losses, reduced prosperity, or strategic disadvantages. In addition, incumbents may promote transition pathways in support of low-carbon solutions that require new investments within their product portfolio. To gain public support for such beneficial transition pathways, or obtaining public funding, arguments may also mirror downsides of climate policies, by in turn emphasizing high societal gains. A specific transition pathway would then, for example, sustain jobs and wealth of regions, or be of strategic relevance for the entire country, whereas absent public funding would render the transition infeasible. Other practical attempts to acquire compensation may comprise lawsuits against governments, or influence via participation in commissions and expert bodies. Policymakers that are subject to these strategies are in difficult positions. Future transition pathways and their strategic implications are inherently uncertain, while an improved assessment may require potentially biased or incomplete information

[6]The following list of discourses in adapted to the specific context of this Section. A fourth option, *surrender to climate change*, it left out completely based on the premise that the net-zero goal is generally accepted.

from incumbents. A study on the heating sector transition in the UK describes such uncertainties about potential pathways in detail, and argues that promoted special interests may even increase uncertainties (Lowes et al., 2020).

These goals and strategies of incumbents are already visible in the emerging discourse around hydrogen. While fostering hydrogen to achieve net-zero is widely accepted as an important measure to achieve this goal, a controversial discussion emerged around its use in different sectors, the preferred production method, and the desirability of hydrogen imports (see Chapter 5). Especially *non-transformative solutions* appear within the German hydrogen discourse. For example, actors from the gas and heat sector advocate to blend hydrogen into the existing natural gas grid, as this would lead to direct emission reductions, while only incremental technical adjustments would be necessary. However, this proposal neglects that green hydrogen may potentially remain scarce may thus be more urgently needed in difficult-to-decarbonize sectors. Technological optimism surrounds the promotion of low-carbon blue hydrogen, as this would require commercial carbon capture and storage facilities that have remained in pilot stages for decades, while neglecting potentially large carbon emissions. A final example are overly optimistic expectations about large-scale and cheap hydrogen imports to satisfy larger parts of Germany's energy demand. *Redirected responsibility* and *emphasized downsides* of climate policies are less used delay strategies.

Instead, advantages of hydrogen are frequently highlighted, as hydrogen would provide new jobs, increase Germany's prosperity by manufacturing and exporting hydrogen technology, and lead to strategic benefits by decreasing fossil fuel imports. While these expectations are generally plausible, they partially occur in conjunction with arguments that detract from electrification as a potentially more efficient solution. This particularly applies to incumbents in sectors where hydrogen is generally more compatible with the current business models. Especially the gas sector would benefit from a large-scale hydrogen economy as this would build on the existing gas infrastructure that would otherwise become obsolete. Optimistic prospects of a hydrogen economy are also widely used to justify public funding for sectoral transitions. Incumbents have organized in multiple interest organizations, such as the global Hydrogen Council, Hydrogen Europe, or the European Clean Hydrogen Alliance. Incumbents are also members of The German National Hydrogen Council, a body that was established to advise the German government.

In summary, the example of the discourse around hydrogen illustrates the complexities of a discourse on a potential (technical) solution that contributes to achieve net-zero. While the deployment of hydrogen may be urgently necessary in some sectors, it may be a non-transformative solution in others. Potential benefits that apply to hydrogen in general are mobilized as arguments for specific (sectoral) uses, or potentially carbon emitting production methods. Similar discursive patterns may evolve around other net-zero innovations, for example related to efficiency (e.g. by promoting higher efforts of other sectors, or suggesting to wait for the development of new technologies), or around negative emissions (e.g. claiming the own sector as particularly eligible, or emphasizing high costs of emission reductions).

Policymakers operate under large uncertainties and are subject to interests of vocal incumbents. Finding practically applicable strategies that support the decision-making processes of policymakers is thus challenging. One approach could be to support the knowledge generation of policymakers in order to improve their judgment on the plausibility of narratives that occur in discourses around net-zero innovations. Enhancing science-based policy advice is one potential option. Knowledge could be obtained from independent universities, research institutes and other experts without commercial interests. However, scientific approaches may decrease, but never fully offset remaining uncertainties. Assumptions e.g. about underlying net-zero scenarios can, however, be transparently communicated, and their realization may be estimated in their likelihood. Expert advisory bodies are one option to institutionalize this. While robust knowledge may reduce uncertainties, its sole existence does not guarantee that policymakers are exposed to it. A legally required evaluation of proposed policies by independent research institutes on the basis of transparent and previously defined criteria followed by a public debate could be one option to ensure that policymakers are confronted with the most neutral knowledge available.

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7 Statement of contribution

The author of this dissertation created all chapters in collaboration with other co-authors. One advisor to this thesis, Prof. Dr. Jan Steckel, contributed to the Chapters 2 and 3. The specific contributions of all co-authors to the contents are detailed below.

Chapter 2: Contributions to the chapter *Carbon Price Floors and Low-Carbon Investment: A Survey of German Firms* by the authors Nils Ohlendorf, Christian Flachsland, Gregory Nemet, and Jan C. Steckel. The initial research idea stems from Christian Flachsland, Gregory Nemet, and Jan C. Steckel and was further refined by all authors. All authors jointly created the research design. Nils Ohlendorf developed the analytical model and the survey, managed the survey dissemination and communication with the participants, conducted the data analyses, and created all tables and figures. Nils Ohlendorf wrote most parts of the paper, Jan C. Steckel contributed parts of the discussion. All authors edited the paper, provided feedback on all previous working steps and especially on the survey design, and jointly interpreted the findings.

Chapter 3: Contributions to the chapter *The Political Economy of Coal Phase-Out: Exploring the Actors, Objectives, and Contextual Factors Shaping Policies in Eight Major Coal Countries* by the authors Nils Ohlendorf, Michael Jakob, and Jan C. Steckel. The initial research idea stems from Nils Ohlendorf and was iterated among the author team. All authors jointly created the research design. Nils Ohlendorf developed the survey, managed the survey dissemination and communication with participants, conducted the data analyses, and created all tables and figures, and wrote the paper. All authors edited the paper, provided feedback on all previous working steps and especially the survey design, and jointly interpreted the findings.

Chapter 4: Contributions to the chapter *The political economy of coal in India - Evidence from expert interviews* by the authors Lorenzo Montrone, Nils Ohlendorf, and Rohit Chandra. The initial research idea stems from Lorenzo Montrone and Jan Steckel. Lorenzo Montrone and Nils Ohlendorf created the research design and conducted the interviews. Lorenzo Montrone managed the communication with interview participants, analyzed the data, wrote the paper, and created all tables and figures. Nils Ohlendorf provided feedback on all these steps, especially edited the text, and contributed parts of it. Lorenzo Montrone and Nils Ohlendorf jointly interpreted the findings. Rohit Chandra supported the interpretation of the findings and edited parts of the text.

Chapter 5: Contributions to the chapter *Conceptualizing Multi-Sector Transitions: the Discourse on Hydrogen in Germany* by the authors Nils Ohlendorf, Meike Löhr, and Jochen Markard. The initial research idea stems from Nils Ohlendorf. Nils Ohlendorf and Jochen Markard created the research design. All authors jointly developed the codebook and the conceptual framework. Nils Ohlendorf complied, coded, and analyzed the newspaper articles, created all tables and figures, and wrote the paper. All authors edited the paper, provided feedback on all previous working steps, double checked the coding, and jointly interpreted the findings.

8 Tools and resources

This dissertation was written on the cloud-based LaTeX editor Overleaf, using the pdfLaTeX compiler, and the TeX Live version 2020. The Chapters 2, 3, and 5 were written and complied using the same resources as this dissertation, while Chapter 4 was written in Mircosoft Word as part of Microsoft Office Professional Plus 2016. All chapters are included as Pdf versions to this document. The references were managed using Zotero 5.0.96.2.

The data processing and calculations were done using Stata 16, R, and Microsoft Excel. Figures were initially created using Stata 16, R, or Microsoft Power Point, and afterwards manually edited using Inkscape 0.92.

The online survey mails for Chapter 2 and 3 were managed using Python 3 and Microsoft Outlook, respectively. For Chapter 4, interview transcripts were created using the software package Dragon NaturallySpeaking, and the interview notes were organized using Microsoft OneNote. The coding of newspaper articles in Chapter 5 was conducted in MAXQDA 2020.