IIIEE Theses 2020:39

The cost of phasing out coal

Quantifying and comparing compensation costs of coal phase-out policies to governments

Lola Nacke

Supervisors

Prof. Dr. Aleh Cherp
International Institute for Industrial Environmental Economics (IIIEE), Lund

Dr. Jessica Jewell
Chalmers University of Technology, Gothenburg

Thesis for the fulfilment of the
Master of Science in Environmental Sciences, Policy & Management (MESPOM)
jointly operated by Lund University – University of Manchester -
University of the Aegean – Central European University

Lund, Sweden, June 2020

Erasmus Mundus Masters Course in Environmental Sciences, Policy and Management

MESPOM

This thesis is submitted in fulfilment of the Master of Science degree awarded as a result of successful completion of the Erasmus Mundus Masters course in Environmental Sciences, Policy and Management (MESPOM) jointly operated by the University of the Aegean (Greece), Central European University (Hungary), Lund University (Sweden) and the University of Manchester (United Kingdom).

Published in 2016 by IIIEE, Lund University, P.O. Box 196, S-221 00 LUND, Sweden,
Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

ISSN 1401-9191

Acknowledgements

I am incredibly thankful to my supervisors Jessica and Aleh, who have supported and challenged me throughout these last two years. Thank you for your guidance and mentorship, without which I would not be where I am today. You have not only enabled me to complete this thesis, but also inspired me to take the next step. I am excited to keep working with you!

I also want to thank Bea and Shiza for reading my drafts – without your comments this thesis would not be the same.

Finally, I want to thank my friends and family who have been there for me in these turbulent times. Especially, thanks to all the Lundelirium leftovers and to Charlie.

Abstract

To reach internationally agreed climate targets, it is especially important to phase out coal-powered electricity generation in favour of low-carbon technologies. Several governments have pledged to phase out coal power. However, coal phase-out is hindered by resistance of negatively affected workers, companies and regional governments. To reduce such resistance and to increase fairness within the transition process, some governments pair coal phase-out pledges with compensation schemes for affected actors. The costs of such schemes may make coal phase-out unfeasible or too expensive as a climate mitigation measure. These costs have not been investigated so far.

This thesis conducts a comparative analysis of Germany, Slovakia, Greece, Finland, Spain and Canada. It quantifies avoided emissions and compensation costs of each coal phase-out pledge and compares compensation cost per avoided ton CO_2 emissions across all countries, similar to a marginal abatement cost curve (MAC). Compensation cost per unit of avoided emissions is higher in Germany, Slovakia and Spain, and lower in Canada, Finland and Greece. Depending on the context of each country, different factors drive compensation MAC: for instance, whereas costs in Finland arise mainly to compensate district heating companies for additional expenditure to replace coal with low—carbon technologies, the Spanish government mainly compensates coal-dependent regions and coal workers.

More generally, the thesis contributes to more accurately accounting the costs of decarbonization to governments and thus advancing the understanding of the political feasibility. For instance, considering that several measures need to be implemented simultaneously to decarbonize electricity systems, governments need to bear costs of these measures simultaneously. Compensation costs to phase out coal power is part of these costs. Depending on the financial capacities of governments, this may negatively affect the feasibility of decarbonization.

Keywords: Political feasibility, decarbonization, distributional costs, coal phase-out, marginal abatement cost

Executive Summary

To achieve rapid decarbonization in line with limiting global average temperature increase to agreed upon levels, it is necessary to implement several decarbonization measures. One of the most urgent measures is phasing out coal-powered electricity generation. However, their political feasibility, i.e. whether relevant actors are able to implement these measures, is still poorly understood. Political feasibility depends on the cost of a measure and the capacity of relevant actors to bear these costs.

A currently widely used metric in emission mitigation is marginal abatement cost (MAC), which calculates costs of a measure per unit of avoided emissions. This concept calculates cost of emission mitigation as aggregate costs to society but does not consider how these costs are distributed across different societal groups. Depending on the measure, specific groups may significantly lose and others may benefit, still leading to overall negative aggregate costs.

Countries aiming to phase out coal-powered electricity generation have started to adopt compensation schemes for negatively affected actors of coal phase-outs, redistributing the costs of coal phase-out across societal groups. Such compensation may have a twofold effect on the feasibility of phasing out coal: First, by limiting resistance among negatively affected groups, compensation may enhance the feasibility of phasing out coal. Second, implementing compensation schemes requires financial capacity of governments. Some countries may not be able to afford compensating negatively affected actors, or spending money on compensating affected actors of coal phase-outs may make this money unavailable for implementing other emission mitigation measures.

To understand the costs of compensation schemes to phase out coal and thus contribute to understanding the distributional costs and political feasibility of climate mitigation, this thesis conducts a comparative analysis of coal phase-out policies in Slovakia, Greece, Finland, Spain, Canada and Germany, answering three research questions:

1. What are the avoided emissions of the coal phase-out pledges?
2. How high are the compensation costs of the coal phase-outs?
3. How are compensation costs allocated among different actors and purposes?

It finds that Canada, Germany and Spain face similar costs of climate mitigation measures, roughly about \$10 to \$50 per avoided ton CO_2 emissions, as shown in Figure I. All three compensate affected workers and coal communities as well as utilities for replacing coal with alternative technologies or with gas. Germany additionally compensates energy companies for retiring their power plants and plans to compensate electricity consumers if electricity prices rise due to the coal phase-out.

Slovakia has a comparatively high compensation cost per avoided ton CO_2 emissions, as the amount of avoided emissions is very low, and the upper boundary estimate may include international finance which is not involved in the other countries. Finland faces comparatively low compensation costs per avoided ton CO_2 emissions, arguably as there are no coal communities or mining workers compensated. Instead, compensation is only payed to district heat companies that agree to accelerate their coal phase-out. Finally, Greece yields surprising results: it bears lowest compensation costs per avoided ton CO_2 emissions and lowest total compensation cost even though there is an important domestic coal mining sector, as well as a structurally disadvantaged, coal-dependent region (Western Macedonia). The low observed compensation costs may be explained through the low financial government capacity preventing higher compensation and government ownership of the energy company, through which the government may absorb costs of phasing out coal without transparent compensation.

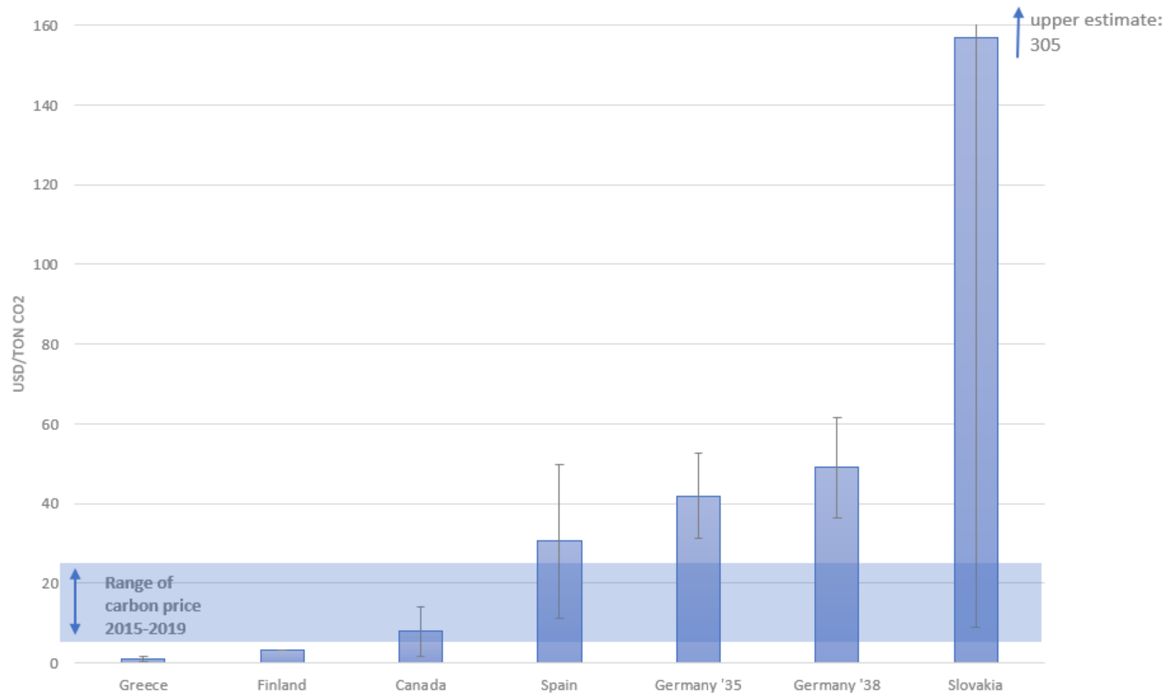

Figure I Compensation costs per avoided ton CO_2 emissions

Sources: Median of upper and lower boundary estimates with error bars: own calculations. The positive error for Slovakia is not shown as it far exceeds the other values. Carbon price in EU ETS: (Markets Insider, 2020).

This thesis also finds that most countries pledge between 0.01% and 0.1% of their national GDP as compensation for affected actors of coal phase-outs. The only estimates significantly above this range are the upper boundary pledge of Slovakia, which includes potential international finance in contrast to the other estimates, and the German compensation scheme, which amounts to 1%-2% of the national GDP.

Future research may aim to gain a broader understanding of the total costs of climate mitigation measures such as phasing out coal to governments, not only including compensation cost but also cost of substituting coal-powered electricity, among others. Future research may apply the findings on costs of phasing out coal to national contexts of major coal consuming countries, comparing and contrasting potential distributional costs with the financial capacity of these governments to estimate the feasibility of phasing out coal in these contexts.

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Abbreviations

BAU	Business as usual
CAD	Canadian Dollar
CCS	Carbon Capture and Storage
CDR	Carbon Dioxide Removal
CHP	Combined Heat and Power
DPO	Deputy Prime Minister's Office
ECSC	European Coal and Steel Community
EPH	Energetický a průmyslový holding
ETS	Emissions Trading Scheme
EU	European Union
FoG	Functioning-of-Government
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HBP	Hornonitrianke Bane Prievidza
IAM	Integrated Assessment Model
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelized Cost of Energy
Mt	Megatons
NECP	National Energy and Climate Plan
NPP	Nuclear Power Plant
NRW	Northrhine-Westphalia
OECD	Organization for Economic Co-operation and Development
PPC	Public Power Corporation
PPCA	Powering Past Coal Alliance
RQ	Research Question
TPES	Total Primary Energy Supply
UK	United Kingdom
USA	United States of America
USD	US Dollar

1 Introduction

1.1 Background and significance

To mitigate climate change and its negative consequences, urgent action is needed; limiting average global temperature increase to 1.5°C by 2100 requires net zero emissions (decarbonization) globally by 2050 (IPCC, 2018). A majority of governments have committed to actions to limit climate change to a global average temperature increase of 2°C (UNFCCC, 2015). However, current political action is insufficient to meet the 2°C temperature target (Jewell & Cherp, 2020; Mundaca et al., 2019; Rogelj et al., 2016; Turnheim & Nykvist, 2019; UNEP, 2019).

To support efficient policymaking towards rapid decarbonization, researchers work on developing mitigation pathways, consisting of many different measures that need to be applied simultaneously. Integrated assessment models (IAMs) are commonly used to and valuable for constructing decarbonization pathways (Jewell & Cherp, 2020; Mundaca et al., 2019; Turnheim & Nykvist, 2019). However, such models may not depict realistically achievable pathways as they only include economic and technological constraints but do not consider other possible constraints arising from social acceptability or political feasibility (Jewell & Cherp, 2020; Riahi et al., 2015). This means that some components of IAM-based decarbonization pathways may be technically feasible but difficult to implement in the real world due to political and social barriers to implementation. Such barriers could include resistance of affected actors of energy transitions, such as fossil fuel companies losing revenue, or residents who do not want wind turbines to be built in the vicinity of their houses, among others.

This thesis examines one of the most important climate mitigation actions: coal phase-out. Among available climate mitigation measures, it is especially important to phase out coal-powered electricity generation in favor of low-carbon electricity sources (IPCC, 2018, p. 15). Technological and economic drivers of coal phase-outs, such as increased economic competitiveness of renewables (Culver & Hong, 2016), should render this measure technologically and economically feasible. However, social and political constraints prevent the phase-out from taking place. These constraints include resistance from affected actors, such as coal workers, local governments of coal-dependent regions, and utilities (Baker, 2018; Meng & Rode, 2019; Vögele et al., 2018). Phasing out coal would prove costly to these actors, which they might not be willing or capable to bear. National governments and international organisations such as the EU have announced financial compensation for negatively affected actors, spending scarce capital with the aim of accelerating coal phase-outs.

Analyzing compensation schemes for coal phase-outs contributes to a broader, better understanding of its political feasibility. Currently, the political feasibility of achieving climate targets is not fully understood (Jewell & Cherp, 2020). According to Jewell and Cherp (2020), political feasibility is determined by the costs of climate mitigation measures and the capacity of relevant actors to bear these costs, depending on the context in which they are to be implemented (see also: Jewell et al., 2019). In other words, the feasibility of climate mitigation depends on its costs, but costs *to whom*?

A large body of research quantifies aggregate social costs of climate policies, measured for instance as loss of consumption (Riahi et al., 2015). However, such costs are not distributed equally across society (Markkanen & Anger-Kraavi, 2019). They may disproportionally fall on a particular country, sector or social group. There is no systematic understanding of such distributional costs of climate mitigation or energy transition despite the fact that if such costs are high, they may generate resistance and stall the transition (see for instance Douenne and

Fabre, 2020). As described above for the case of coal phase-outs, governments may choose to financially compensate negatively affected actors.

1.2 Problem definition

While compensating affected actors may increase acceptability of coal phase-outs, the costs of compensation schemes may affect their political feasibility. For instance, a recent systematic assessment of Powering Past Coal Alliance (PPCA) members (Jewell et al., 2019) shows that phase-out policies were limited to high-income countries, suggesting their potentially high political and economic costs. As more governments, especially major coal users, need to implement coal phase-outs, would they be able to afford compensation schemes?

This leads to several questions: How much does it cost for governments to compensate affected actors of coal phase-outs, and does this seem attainable for major coal using countries such as South Africa, China, or India? If governments allocate scarce political capital to accelerate coal phase-outs, are they able to financially support the implementation of these additional climate mitigation measures? Heinisch, Holtemöller and Schult (2019) also raise the question of how the cost of coal phase-out policies compares to the cost of other emission mitigation measures, which may not cause job losses and thus not require compensation to the same extent.

Answering these questions is relevant to assess the political feasibility of mitigating global climate change as outlined by IAM-based pathways: According to Jewell and Cherp (2020), the costs of climate mitigation measures and the capacity of the relevant actors to bear these costs, depending on the context in which they are implemented, determine whether a measure is feasible (see also: Jewell, Vinichenko, Nacke, & Cherp, 2019). Jewell and Cherp (2020) argue that the political feasibility of climate mitigation is still poorly understood and requires further research.

To address the above-mentioned problems, this thesis analyzes coal phase-out pledges that are coupled with compensation schemes for affected actors. It quantifies avoided emissions of these phase-out pledges, in relation to how much money governments spend on the corresponding compensation schemes. Quantifying financial compensation schemes for coal phase-outs sheds light on the distributional costs of this climate mitigation measure: the extent to which governments need to redistribute the costs of energy transitions among societal groups indicates the extent of the disproportional allocation of these costs. This improves our understanding of political feasibility in addition to techno-economic feasibility of implementing climate mitigation measures, which may help to build more realistic decarbonization pathways.

1.3 Aim, objective, research questions and audience

By assessing the costs of phasing out coal and comparing them across different contexts, this thesis aims to advance the understanding of the distributional costs and political feasibility of decarbonization measures. To achieve this aim, the objective of this thesis is to develop an analytical framework to assess compensation costs of phasing out coal. This framework draws from the existing marginal abatement cost (MAC) concept, which relates avoided emissions of climate mitigation measures to the costs of such measures. To understand why compensation costs of phasing out coal may differ across governments, this thesis also examines and compares the allocation of costs among different actors and purposes in different contexts (see more in section 3.1).

With the help of this framework, this thesis answers three research questions (RQs):

1. What are the avoided emissions of the coal phase-out pledges?
2. How high are the compensation costs of the coal phase-outs?

3. How are compensation costs allocated among different actors and purposes?

This thesis applies these RQs to countries that phase out coal and compensate affected actors, compares the results across the different contexts and to the MAC of other climate policies.

This knowledge benefits academics, as this thesis contributes to literature on feasibility of energy transitions and decarbonization pathways by providing a way to assess compensation costs in relation to avoided emissions of decarbonization measures. In line with Jewell and Cherp (2020), better understanding the costs of observed cases of climate action can help to better understand their current "feasibility frontier" (p. 7), in other words whether an action is feasible depending on its costs and the capacity of relevant actors to carry these costs in specific national contexts.

Answering these RQs can also provide useful insights for practitioners such as policy makers, environmental NGOs or consultants, who may gain better understanding of avoided emissions and costs of coal phase-outs and thus be able to better prioritize different policy measures and budgeting towards reaching climate targets.

1.4 Ethical considerations

The research design has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee. However, in using the results of the thesis, for instance to inform decision making, limitations of this study (discussed in the following sub-section as well as throughout the results section) need to be considered. Justice considerations and co-benefits of coal phase-outs and compensation schemes are not included in this study but may be highly relevant to political decision making.

1.5 Scope and limitations

This thesis focuses on coal phase-out pledges of national governments coupled with compensation schemes for affected actors. It includes only countries that fulfilled these conditions by January 2020. Countries announcing coal phase-outs and compensation schemes after this date were not considered, as this would not have left enough time to ensure thorough data collection and analysis. This case selection leads to a systematic bias, as it excludes countries where coal was or is phased out without transparently compensating affected actors. For instance, governments may pay standard unemployment benefits for which coal workers are eligible when the coal industry is phased out. However, such standard unemployment benefits may not be labelled as occurring due to the coal phase-out. Coal phase-outs may thus increase costs to governments even in countries without transparent compensation schemes, which are not included in this thesis.

It also excludes major coal consumers that have not announced coal phase-outs but where phasing out coal is most relevant from an emissions mitigation perspective and where coal use may have declined due to non-policy factors (e.g. in the US). This limits the contribution of this study as it does not lead to conclusions on the feasibility of phasing out coal in these highly relevant contexts. Section 6 reflects on these limitations and develops further RQs to complement this study.

Due to international case selection, several data limitations need to be considered. For instance, not all countries' public documents are available in English. Governments might also differ in their transparency, which may affect accessibility and credibility of documents. These limitations are manageable since the only non-EU country, Canada, has English as its working language. For EU countries where the author does not speak the national language (Finland, Slovakia, Greece), international documents such as National Energy and Climate Plans (NECPs) submitted to the EU in December 2019, presentations given within EU working groups or press releases from government websites written in English provided reliable data sources.

By calculating compensation costs of coal phase-outs, this thesis aims to contribute to understanding the feasibility of climate mitigation. However, costs of compensation schemes only capture part of the total costs of climate mitigation policies to governments. Additional costs may include subsidies for low-carbon technologies replacing fossil fuels, among others. To further advance understanding of the feasibility of climate mitigation, calculating total costs of governments of specific mitigation measures may be helpful.

One criticism of focusing on the costs of coal phase-out compensation schemes is that both phasing out coal and projects financed through compensation schemes may have co-benefits that are left out of the assessment. Phasing out coal may for instance reduce public health costs due to reduced air pollution, compensation schemes may be used to build infrastructure projects, education facilities or alternative (low-carbon) industries, which can lead to economic development. Thus, not accounting for these co-benefits may lead to an over-emphasis of phase-out costs. While acknowledging this criticism, I choose not to quantify co-benefits. The benefits of coal phase-out are widely known, but similarly to other climate measures, these benefits speak to *desirability*, not *feasibility* of coal phase-out. The contemporary thinking clearly separates these concepts. For instance, Jewell and Cherp (2020) note that even very desirable policies may not be feasible. This is because desirability is usually calculated in a society-wide (often global) context, whereas feasibility is determined by the costs to individual actors (in my case, the state) who may not have the capacity to bear these costs.

This thesis is also not able to exclude the possibility of double counting. Some projects which governments may say are financed as part of their coal phase-out might have been planned prior. This was an issue in Germany, where several infrastructure projects that were already planned in the affected regions were allocated to the coal phase-out. In Canada, government support for a geothermal facility is mentioned as part of the coal phase-out, but also in connection to other energy-related policies (these findings are also mentioned in section 5). Additionally, several of the compensation schemes reviewed include unemployment benefits for laid-off workers. To transparently address these limitations, I add sub-sections discussing the probability with which these aspects may influence the results of each country.

This thesis uses current government pledges and policies. It is possible these policies will not be implemented as currently foreseen, due to a change of governing parties or a change of economic conditions, as is currently caused by the Covid-19 pandemic.

1.6 Structure

Section 2 reviews literature on decarbonization pathways and the feasibility of energy transitions, embedding this thesis within this framework. It also reviews assessments of past coal phase-outs and the role of compensation schemes in coal phase-outs. Building on the reviewed literature, section 3 describes the analytical framework and methodological approach. Section 4 presents the results for individual countries, and section 5 compares these results. Section 6 discusses the findings, by comparing them to costs of other emission mitigation measures. This thesis concludes with recommendations for further research.

2 Literature review

A wide range of academic literature discusses the urgency and feasibility of climate change mitigation and energy transitions from different perspectives. This thesis is embedded within this literature, drawing from previous studies' findings on the feasibility of energy transitions and phasing out coal. It aims to contribute to this literature by quantifying the compensation costs of phasing out coal. The following sub-sections review current knowledge in this field, divided in two main parts: the first part discusses the political feasibility of energy transitions as a climate mitigation measure (section 2.2). This section identifies a knowledge gap as the costs of mitigation measures, which partly determine their political feasibility, are not yet fully understood.

The second part reviews studies of current and past coal phase-outs to determine which costs may be relevant when phasing out coal. Finding that these costs have not been systematically assessed to date (section 2.3), this thesis pursues to examine the costs of current coal phase-out policies to make a contribution towards better understanding the political feasibility of coal phase-outs as emission mitigation measures and ultimately towards understanding the political feasibility of decarbonization.

2.1 Feasibility of energy transitions

This section first discusses the importance of energy transitions in decarbonization pathways. It then reviews conceptualizations of the feasibility of energy transitions. It finally explores existing knowledge on the costs of energy transitions and the capacities of relevant actors to carry these costs, which determine the political feasibility of energy transitions.

2.1.1 Energy transitions in decarbonization pathways

To limit global average temperature increase to 1.5° or 2° with limited overshoot, it is necessary to implement a variety of measures in different sectors, such as energy demand reduction, urban planning, decarbonization of the transport sector and changes in land use (Hammond & Rossi, 2017; IPCC, 2018). One important aspect are transitions from carbon-intensive to low-carbon energy sources, "requir[ing] large-scale changes to established energy systems" (Li & Strachan, 2017, p. 107). This seems especially challenging as global energy demand grew in 2018 and 70% of this growth was met by fossil fuels, mostly gas, but also coal (IEA, 2019). Additionally, "coal-fired power generation continues to be the single largest emitter, accounting for 30% of all energy-related carbon dioxide emissions" (IEA, 2019). It is thus especially relevant to phase out coal-fired power generation. The IPCC endorsed multiple pathways that are in line with reducing climate change to 1.5°C under different conditions, for instance assuming significant energy demand reduction or the availability of technological carbon dioxide removal (CDR). All these pathways steeply reduce the use of coal in electricity generation to 0-2% of global electricity generation by 2050 (IPCC, 2018, p. 15).

The IPCC identifies decarbonization pathways generated by different Integrated Assessment Models (IAMs). IAMs inform many global studies on climate change mitigation. They allow researchers to project the potential evolution of global greenhouse (GHG) emitting systems such as agriculture, land use and the energy system over a certain period of time and under different assumptions (Gambhir et al., 2019). Often, for instance, models operate under the assumption that emission mitigation pathways should be cost-minimizing (Fragkos & Kouvaritakis, 2018; Napp et al., 2017). IAMs are used to assess how fast emissions need to be reduced to limit climate change to 1.5°C, and which technologies need to be introduced or reduced to achieve these emissions reductions (Jewell & Cherp, 2020). They provide useful information to researchers and practitioners as to which fuel or technology mixes may be plausible in the future, how the transition from current to future mixes may develop and what this may cost (Fragkos & Kouvaritakis, 2018; Napp et al., 2017). As IAMs have been used for quite some time, informing for instance already the second IPCC report in 1996 (Gambhir et al., 2019), they have become more sophisticated over time.

However, there remain several criticisms related to models' assumptions and outcomes. Li and Strachan (2017), for instance, criticize that models usually assume a "first best" world in which actors always make cost-efficient decisions and governments are able and willing to enact policies despite resistance from vested interests, i.e. "special interests of particular social groups" that may influence energy policies (Cherp et al., 2017, p. 613). IAMs have also been criticized for overestimating the role of certain low-carbon electricity sources such as biomass and nuclear over solar and wind technologies due to old data and underlying assumptions (Creutzig et al., 2017). Another technology that has been used to criticize IAM-based pathways is carbon capture and storage (CCS) (Gambhir et al., 2019). It is included in some pathways even though the feasibility of large-scale CCS deployment seems limited due to "problems with funding, commercial viability, legal risks, and limited political commitment" (Nykvist, 2013). Notwithstanding the usefulness of model-derived pathways for decision making, researchers thus argue that the shortcomings of these approaches need to be recognized and call for complementing IAM-based information through studies on social and political constraints in addition to techno-economic ones considered by IAMs (Oei, Brauers, Herpich, et al., 2019).

2.1.2 The feasibility of energy transitions

IAMs help to determine which combination of climate mitigation measures implemented within a certain timeframe can achieve a certain level of emission reductions. Scholars question, however, to what extent actors are able to implement these measures, i.e. to what extent these measures are feasible. An outcome is "politically feasible if there is an agent or group of agents who have the capacity to carry out a set of actions which will lead to that outcome in a given context" (Gilabert & Lawford-Smith, 2012; Jewell & Cherp, 2020, p. 3). In other words, if constraints outside the control of the decisionmaker hinder a measure from being implemented, it is unfeasible (Jewell & Cherp, 2020). IAMs determine the feasibility of emission mitigation pathways through modeling geophysical, technical and economic parameters. However, whereas the thus obtained solutions might be technically and economically achievable, they are not necessarily feasible as political and social aspects may be unaccounted for (Gambhir et al., 2019; Jewell & Cherp, 2020; Riahi et al., 2015; Rogelj et al., 2018).

Whereas scholars widely agree that IAM-based information needs to be tested against other interpretations of feasibility, their conceptualization and operationalization of this concept may differ. They may for instance study "physical, technical, socio-economic [or] sociopolitical" aspects of feasibility (Jewell & Cherp, 2020; Kriegler et al., 2018). Based on their operationalization of feasibility, scholars choose different approaches of complementing existing IAM-based assessments.

One such approach is to compare projected energy transitions against historical developments (Napp et al., 2017). This may help to understand whether the pace and scale of an energy transition proposed by an IAM is precedented and thus whether energy systems and affected actors seem to be capable of supporting this transition. Napp et al. (2017) find that required rates for energy transitions developed by a selected IAM exceed precedented growth rates considerably, thus resulting in higher average global temperature by 2100 or in much higher costs of accelerating the transition. There are, however, also limitations to these historical comparisons. The feasibility of energy transitions is determined through several factors, such as the costs of installing low-carbon technologies, and the capacity of the relevant actors such as governments, energy utilities, etc. to bear these costs (Jewell & Cherp, 2020). These costs and capacities may change over time (see also section 2.1.3). Even though change rates may thus be unprecedented as they may not have been feasible in the past, they may become feasible in the future if costs of alternative technologies decrease or the capacities of relevant actors increase.

Other scholars thus focus on the interaction of actors in different sectors and whether actors support or resist climate policy which may affect the feasibility of low-carbon energy transitions. "Political feasibility is […] highly dependent on actors with substantial influence, power, and vested interests – whether in politics, industry, civil society, or knowledge production." (Turnheim & Nykvist, 2019). While some actors may benefit from transitioning to low-carbon energy sources, such as renewables producers, others may incur losses, such as the fossil fuel industry. The degree to which affected actors influence decision-making processes depends on the institutional setup in different countries, which may foster different patterns of interactions between states and relevant industries (Cherp et al., 2017, 2018; Ikenberry, 1986). States and industries for instance interact differently in coordinated compared to liberal market economies, which may affect energy transitions pathways (Geels et al., 2016; Rentier et al., 2019).

The extent to which actors' interests may affect the feasibility of energy transitions also depends on the relative power of these actors. Incumbents, dominant actors in established energy systems, have financial resources and technological knowledge that may support energy transition goals (Cherp et al., 2017). However, they are also capable of self-reproduction and resisting states' goals if they feel threatened by them. This can negatively affect the feasibility of energy transitions and lead to technological lock-in of traditional energy sources (Cherp et al., 2017). Scholars adopting a socio-technical perspective focus on the likelihood of advocacy coalitions, groups formed by actors with similar interests for or against certain energy technologies, with the aim of gaining a larger influence on decision-making process (Turnheim & Nykvist, 2019). Cherp et al. (2017) argue that while interest groups may affect energy politics, the existence of interest groups alone does not completely explain why an energy transition takes place in one context and not in another, as energy transitions are influenced by several mechanisms simultaneously.

According to Jewell and Cherp (2020), three questions should be answered to unpack these different mechanisms that affect political feasibility of climate mitigation measures: Feasibility of what, feasibility for whom and feasibility when and where. "Feasibility of what?" defines the measures that need to be implemented, for instance using IAMs. As shown in section 2.2.1, IAMs identify energy transitions, and specifically phasing out coal, as significant climate mitigation measures. "Feasibility for whom?" identifies the actors that are relevant to implement a measure. "Feasibility when and where?" relates to the context in which a measure is to be implemented. The context is significant as Jewell and Cherp (2020) argue that the political feasibility of emission mitigation depends on the cost of implementing the measure and on the capacity of relevant actors to carry these costs. Both capacities and costs are context-dependent and can change over time and across different regions and countries. Figure 1 visualizes this concept: the two axes represent the two factors influencing the feasibility of climate mitigation measures, costs and capacities (Jewell et al., 2019; Jewell & Cherp, 2020). By observing current cases of climate action and determining what their costs are and what the capacities of the relevant actors are that carry these costs, a feasibility space can be identified, that is bordered by a feasibility frontier. Both space and frontier are dynamic, i.e. they may need to be adjusted if further observed cases of climate action emerge.

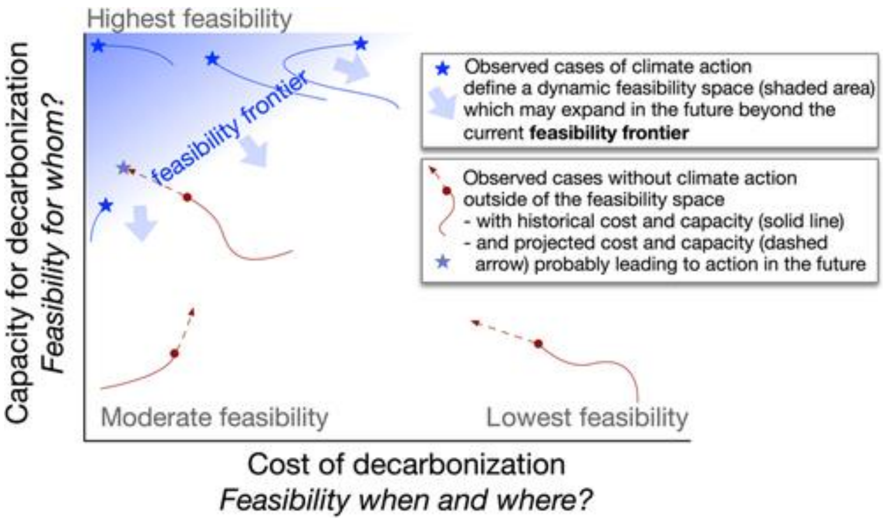


Figure 2-1 Political feasibility space and feasibility frontier

Source: (Jewell & Cherp 2020, p. 7)

2.1.3 Distributional costs of energy transitions and capacities of relevant actors

To understand the political feasibility of climate mitigation, it is thus necessary to understand the costs of specific climate mitigation measures and the capacities of relevant actors. As Jewell and Cherp (2020) argue, this is not yet fully understood and requires further academic studies. There are for instance different ways to conceptualize and quantify the costs of energy transitions and the capacities of different actors.

IAMs often focus on necessary investments and operating costs of the energy system. Energy system costs include for instance the levelized cost of energy (LCOE) (Nuclear Energy Agency, 2019; Wang & Chen, 2017): LCOE includes capital, operating and maintenance expenditures, leading to a cost of energy per megawatt-hour (mWh) (Gillingham & Stock, 2018). Energy systems costs also include costs of transmitting and distribution of energy and the costs of connecting power plants to the transmission grid (if this is not included in the LCOE) (Nuclear Energy Agency, 2019; Wang & Chen, 2017). Fragkos and Kouvaritakis (2018) for instance include capital, operation and maintenance, fuel and carbon costs of technologies to develop their pathways.

To make choices between different climate mitigation measures, decision makers do not only rely on model-derived pathways, but also on the marginal abatement cost (MAC) of different emission mitigation measures: This concept calculates costs of different energy technologies, such as LCOE, per abated ton of CO_2 emissions (Gillingham & Stock, 2018; Kesicki & Strachan, 2011; WALGA, 2014). The MAC of different climate policies is compared in Table 2-1. Similar to IAMs, MAC calculations consider techno-economic cost such as LCOE (Gillingham & Stock, 2018; Kesicki & Strachan, 2011; WALGA, 2014). These techno-economic costs of energy sources may change over time. Both IAM-based pathways and MAC calculations have been criticized for the use of old data, which may not adequately represent current costs and thus significantly deter their outcomes (Creutzig et al., 2017; Gillingham & Stock, 2018). Even though some more advanced MAC calculations have started to incorporate other types of costs such as job losses (see for instance Heinisch et al., 2019), this is not usually captured by standard MAC calculations.

Table 2-1 Static costs of policies based on a compilation of economic studies

Policy	***Estimate (USD2017/ton CO_{2e})***
Behavioral Energy Efficiency	-190
Corn starch ethanol (U.S.)	-18 to +310
Renewable Portfolio Standards	0-190
Reforestation	1-10
Wind Energy Subsidies	2-260
Clean Power Plan	11
Gasoline Tax	18-47
Methane Flaring Regulation	20
Reducing Federal Coal Leasing	33-68
CAFE Standards	48-310
Agricultural Emissions Policies	50-65
National Clean Energy Standard	51-110
Soil Management	57
Livestock Management Policies	71
Concentrating Solar Power Expansion (China and India)	100
Renewable Fuel Subsidies	100
Low Carbon Fuel Standard	100-2,900
Solar PV Subsidies	140-2,100
Biodiesel	150-250
Energy Efficiency Programs (China)	250-300
Cash for Clunkers	270-420
Weatherization Assistance Program	350
Dedicated Battery Electric Vehicle Subsidy	350-640

Source: Gillingham & Stock (2018), p. 59

IAMs or MAC calculations often conceptualize costs as aggregate losses to society. For instance, models that calculate macroeconomic impacts of climate mitigation may conceptualize costs as GDP losses (Riahi et al., 2015). Often, models operate under cost-minimizing assumptions, i.e. they calculate emission mitigation pathways which incur least costs to society overall (Fragkos & Kouvaritakis, 2018; Napp et al., 2017). However, macroeconomic impacts may disproportionately and distributionally affect different groups in societies, or different regions. Even though a certain emission mitigation pathway is least expensive on an aggregate, global level, certain regions may incur larger costs than others (Leimbach & Giannousakis, 2019). Markkanen and Anger-Kraavi (2019), for instance, argue that low-carbon transition may especially negatively affect economies of "energy exporting developing countries". Additionally, even if the total cost of emission mitigation in poor countries may be lower than in developed countries, the opportunity cost of implementing these measures may be higher as this may negatively affect economic growth and poverty reduction in these contexts (Kverndokk, 2018).

These considerations give rise to the ideas of burden or effort sharing in global decarbonization, which relate to both "sharing of financial burdens […] and mitigation efforts" (Leimbach & Giannousakis, 2019). Instead of cost minimization, some studies and models develop emission mitigation pathways based on equity principles which aim to achieve distributive justice or fairness of implementing climate mitigation measures, i.e. to equitably distribute financial and emission mitigation burdens among countries (Höhne et al., 2014; Kverndokk, 2018; Leimbach & Giannousakis, 2019; van den Berg et al., 2019). Studies may operationalize equity or fairness differently by applying different equity principles, among others based on historical responsibility or ability of countries to pay (Höhne et al., 2014; van den Berg et al., 2019). Some models may consider international transfers as a way to mitigate distributional effects of climate mitigation on certain regions (Kverndokk, 2018; Leimbach & Giannousakis, 2019; van den Berg et al., 2019). Such transfers may include technological or financial support for less developed countries, which Kverndokk (2018) categorizes as mitigation transfers, adaptation transfers or development aid. Some models may also consider intergenerational equity principles (Bovenburg & Goulder, 2003; Kverndokk, 2018).

In addition to distributional effects on different regions, different actors within one country may also be distributionally affected by climate policies. Scholars for instance studied the distribution of climate policies' costs "across household income groups […] and across industries" (Bovenburg & Goulder, 2003). Markkanen and Anger-Kraavi (2019) review different types of distributional effects of climate mitigation policies, including job losses and gains in different sectors, or an increase of the costs of essential goods. These may especially affect the most vulnerable societal groups that spend a higher share of their income on these essential goods or lack skills to transition to other jobs. Fullerton (2011, 2017) argues that there are six types of distributional costs which affect different actor groups on national level, summarized in Table 2-2. The type of effect that arises depends on the type of policy and on the product that is affected by the policy, for instance on the price elasticity of demand. In the case of electricity, for instance, consumers are still likely to purchase electricity even if prices rise, leading to potential costs to consumers of energy transitions.

Table 2-2 Six distributional effects of climate policies

Effects	**Group which benefits/ loses**	**Affected actors of energy transitions**
Price increase of (essential) goods	Costs to consumers	Rising electricity prices: costs to electricity consumers
Reduction of producer output	Costs to producers or factors of production	Less fossil fuel use: costs to coal/gas/oil producers and utilities
Scarcity rents	Benefit to government or producers	Rise of CO_2 prices: benefits to governments or companies (depending on ETS)
Reduction of pollution and related public health costs	Benefit to consumer and/or government	Reduction of emissions, reduced diseases and public health costs: benefits to governments
Change of asset value	Benefit or loss to owners of assets	Fossil fuel infrastructure loses value: costs to owners/investors
Costs of transition (capital and labour leaving industry)	Costs to workers, industry/producers	Job losses in fossil fuel production and power plants: losses to workers

Source: developed by the author based on Fullerton 2011, 2017

Table 2-2 also shows that in addition to costs, climate mitigation measures may have co-benefits. Transitioning from fossil fuels to low-carbon energy sources for instance leads to reduced air pollution, which may reduce cases of illness and thus public health costs, or may lead to increased energy access for energy poor groups (Caldecott et al., 2017; Markkanen & Anger-Kraavi, 2019). In addition to public health, negative effects of fossil fuel-based electricity may include damages to harvest (Ernteschäden) and biodiversity losses which may decrease as fossil fuel use is reduced (Matthey & Bünger, 2019). These co-benefits are usually not included in quantitative cost-benefit analyzes that assess the costs of climate policies (Ürge-Vorsatz et al., 2014), even though they may far outweigh the costs of climate mitigation measures (Rauner et al., 2020). At global level, costs of facing the impacts of global warming between 2°C to 3°C have for instance been estimated as high as 5% to 20% of global GDP (Oei et al., 2019). Notwithstanding these co-benefits, their influence on policymakers and public support for climate mitigation remains limited. Concerns over the costs of policies still seem to dominate political decisions over climate mitigation measures (Bernauer & McGrath, 2016; Karlsson et al., 2020). One reason may be that the materialization of co-benefits is further removed from the implementation of the measure itself, whereas costs occur upfront.

Table 2-2 shows costs to energy producers for instance as "reduction of producer output" (decreasing revenue) and "change of asset value": In response to climate policies reducing the use of fossil fuels, part of the existing fossil fuel infrastructure may need to be retired before the end of its useful life. As investors originally expected these assets to generate revenue throughout their useful life, they lose part of this expected revenue as assets are prematurely retired, thus becoming "stranded assets" (Hagen et al., 2019; Hammond & Rossi, 2017). In response to these costs, actors may resist the implementation of climate mitigation measures or demand compensation from governments which implement climate policies: Hammond and Rossi (2017) for instance argue that investors and utilities can be expected to demand compensation from governments for stranded assets. In addition to energy producers, other potentially affected actors of climate mitigation as shown in Table 2-2 may also resist to bear the cost of climate mitigation. By compensating negatively affected, potentially resistant actors, governments may thus enhance energy transitions by making climate mitigation more acceptable to negatively affected groups. Additionally, some may argue that these compensations make climate mitigation measures within countries more equitable, similar to the concept of burden sharing among countries presented above.

Jewell and Cherp (2020) argue that whether a cost becomes a constraint for an actor depends on the actor's ability to bear this cost. This indicates that, while some governments may be able bear costs associated with energy transitions, others may not be able to bear the costs imposed in their context, or they might be dependent on international finance to be able to cover these costs (Willems & Baumert, 2003). The conceptualization of governments' capacities may depend on the researchers' perspective. Jewell et al. (2019) for instance found that the "difficult process of coal phase-out is more likely to be pursued by independent and transparent governments in wealthy countries" (p. 596), which they operationalized as gross domestic product (GDP) per capita (wealth) and the functioning-of-government (FoG) index (transparency and independence). Jewell (2011) assesses capacity in terms of technical, financial and institutional capacity as well as political stability. A country is technically capable to install a nuclear power plant (NPP) if it has the necessary grid size. Financial capacity is indicated through GDP and GDP per capita, which indicates the capacity to invest in the construction of the NPP and the necessary infrastructure. The world bank government effectiveness indicator shows institutional capacity, indicating whether a government can garner international support and private investment. Jewell (2011) also argues that motivation can enable a government to mobilize necessary resources even if its measurable capacities are limited. However, desirability does not necessarily increase an outcomes' feasibility (Gilabert & Lawford-Smith, 2012; Jewell & Cherp, 2020). The concept of capacity thus helps to determine the ability of states to pursue an energy transition even if incumbents or other affected actors may resist this, thus making this transition feasible (Cherp et al., 2018; Jewell & Cherp, 2020)

2.1.4 Summary

The previous sub-sections have shown that low-carbon energy transitions, and especially the phase-out of coal in electricity generation, are important aspects of decarbonization pathways towards limiting global average temperature increase to about 1.5°C, as for instance IAM-based studies show. However, whereas these studies may convey the macroeconomic, aggregate costs, need and timeframe of implementing these measures, they do not consider the distribution of these costs among different actors which may lead to political or social barriers to implementing emission mitigation measures.

As shown above, fossil fuel phase-outs impose costs on different actors, including companies and workers in the respective sector and, potentially, electricity consumers. These affected actors may thus resist energy transition policies, which may be especially successful if advocacy coalitions form and patterns of interaction in countries facilitate access to decision-making processes for affected actors. To prevent such backlashes and enable the accelerated implementation of climate policies given the resistance of (potentially influential) actors, governments may choose to financially compensate them. Jewell and Cherp (2020) argue that the costs of implementing a climate mitigation measure to specific actors and the capacities of these actors, such as governments, determine the political feasibility of climate change mitigation. This means that governments need to have the capacity of bearing costs of compensating affected actors of climate mitigation measures. Even though the costs of several climate mitigation policies have been studied (Gillingham & Stock, 2018), the costs of phasing out carbon-intensive industries such as coal, one of the most pressing emission mitigation measures, is not included in these assessments.

Considering this knowledge gap, this thesis develops a framework to assess the costs of phasing out coal to governments in a way that may be helpful to decision makers and contribute to academic literature on the political feasibility of global decarbonization. Towards this aim, the following sub-section reviews academic and grey literature on current and past coal phase-out policies, gaining an overview of how coal phase-outs and their costs to governments have been previously assessed.

2.2 Phasing out coal

Sub-section 2.2.1 provides an overview of the current global status of the coal sector and current policy approaches to phasing out coal. As the previous section has shown, the costs of coal phase-out policies seem to be yet unknown, which limits the current understanding of the feasibility of phasing out coal use globally until 2050. To confirm this suspected knowledge gap and to develop a framework to address this gap, sub-section 2.2.2 reviews studies of past coal phase-outs to understand how costs of phasing out coal have been previously assessed.

2.2.1 Phasing out coal as a climate mitigation measure

Coal is the largest contributor to global CO_2 emissions (IEA, 2019, 2020b) and phasing out coal use in power generation is one of the most urgent actions on the path to limiting global climate change to 1.5°C (IPCC, 2018). However, to date, coal supplies almost 40% of electricity generation worldwide (IEA, 2020b). Decreasing costs of renewables deployment and shale gas, technological developments such as CCS and energy storage solutions however seem to constitute barriers to further coal expansion even in countries with large shares of coal in their electricity mix, such as India and the US (Oei, Brauers, Herpich, et al., 2019). In India, for instance, 490 GW planned coal capacity has been cancelled between 2010 and 2018 (Schindler, 2019). Between 2015 and 2017, global coal mining has recorded the biggest decline since 1971, as the demand for coal and the number of newly constructed power plants decreased (Oei, Brauers, Herpich, et al., 2019). This observed decline is not only driven by techno-economic factors but also through climate policies, such as capping and pricing CO_2 emissions, emission requirements, and for instance EU regulation prohibiting state subsidies for coal mining (Oei, Brauers, Herpich, et al., 2019; Rentier et al., 2019). This is however not yet in line with emission reduction pathways towards limiting climate change to up to 2° average global temperature increase (Rogelj et al., 2016; Schindler, 2019). Coal phase-outs thus need to be accelerated through further political action.

Indeed, political action seems to increase: In 2017, the United Kingdom (UK) and Canadian governments founded the Powering Past Coal Alliance (PPCA). National, subnational and local governments as well as private actors such as companies that adhere to PPCA principles can join (PPCA, 2020b). Governments joining the alliance "commit to phasing out existing unabated coal power generation and to a moratorium on any new coal power stations without operational [CCS]" (PPCA, 2020b). Currently, 33 national governments are part of the PPCA (PPCA, 2019b). To phase out coal power generation, governments can implement different types of policies. As Figure 2-2 shows, Oei et al. (2019) classify measures as regulatory or price-based instruments. Regulatory instruments such as a fixed schedule for power plant closures ensures an outcome at a certain time, whereas price-based instruments such as pricing CO_2 emissions provides companies with choices, such as fuel switching or installing CCS.

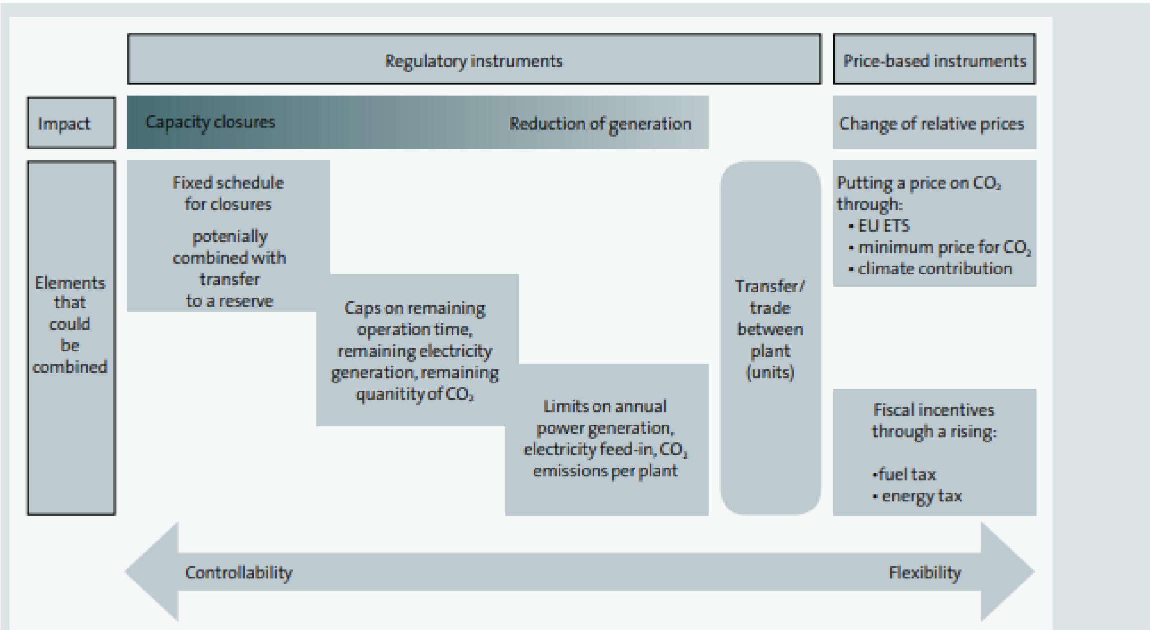


Figure 2-2 Potential elements for policy instruments to reduce the use of coal in the energy sector

Source: Oei et al., 2019

Even though some have greeted the alliance as a "political watershed" at its announcement (Carrington, 2017), others have criticized that several of its members do not burn any coal or already agreed to phase out coal before joining the alliance (Jewell et al., 2019). Blondeel, Van de Graaf and Haesebrouck (2020) argue that having a coal phase-out plan is one indicator of joining the alliance. Additionally, a large share of coal in the domestic energy mix and domestic coal production provide barriers for countries to join the alliance (Blondeel et al., 2020; Jewell et al., 2019). Rentier et al. (2019) also argue that implementing coal phase-outs may be especially challenging for countries with a large share of coal in their energy mix and domestic coal production. This may lead to institutional carbon lock-in: actors of the established coal regime are likely to be powerful and well organized and conduct efforts to maintain the status quo that serves their interests (Blondeel et al., 2020; Rentier et al., 2019). Additionally, a larger share of coal in the electricity mix may lead to higher material costs and stranded assets (Jewell et al., 2019). These factors may partly explain why major coal consuming countries such as India or China are not yet part of the alliance, thus limiting its contribution to global emission reduction and the goal of limiting climate change to 1.5°C (Jewell et al., 2019).

However, in the last year, two countries that face comparatively large barriers to phasing out coal, i.e. a strong coal industry and a large share of coal in the electricity system have joined the alliance: Germany and Greece (Buzatu, 2019; PPCA, 2019a, 2019c; Tsagas, 2019). In both countries, the coal phase-out is implemented simultaneously with a "just transition" approach: Greece already established a National Just Transition Fund (Popp, 2019) and is currently preparing a "Just development transition master plan" (Ministry of Environment and Energy, 2019b) to assess and mitigate negative effects of the phase-out on major coal regions. Germany drafted the coal phase-out legislation according to a report from the Commission "Growth, Structural Change and Employment" (dt.: Kommission "Wachstum, Strukturwandel und Beschäftigung, further: Commission) (Commission, 2019). The Commission's mandate was to develop a coal phase-out and compensation plan that ensures a socially acceptable coal phase-out. This has been called a "just transition" approach by workers' unions and research institutes (Agora Energiewende & Aurora Energy Research, 2019; Just Transition Centre, 2019).

The term "just transition" was originally coined by a trade union movement in the United States (US) in the 1980s as a response to tightening emission legislation that arguably endangered employment in carbon-intensive sectors (McCauley & Heffron, 2018; Newell & Mulvaney, 2013). "Just transition" approaches are called for by affected actors to enable the implementation of climate policies in a socially acceptable and beneficial manner, bridging environmental and justice concerns (G. Evans & Phelan, 2016; Swilling et al., 2016). The term is now also more widely used by politicians and researchers especially in connection with low-carbon transitions and the phase-out of high-carbon industries and sectors that may negatively affect workers and communities (McCauley & Heffron, 2018; Newell & Mulvaney, 2013; Spencer et al., 2018).

It is, for instance, one of the principles of the PPCA to achieve coal phase-outs "in a sustainable and economically inclusive way, including appropriate support for workers and communities" (PPCA, 2020b), to which end they launched a Just Transition Taskforce (PPCA, 2020c). The EU has also proposed the creation of a Just Transition fund as part of its "Green New Deal" (Proposal for a Regulation of the European Parliament and of the Council Establishing the Just Transition Fund, 2020) to support low-carbon transitions in the most coal reliant countries and regions (Morgan, 2020). As indicated above, national governments such as Germany and Greece also implement or plan "just transition" approaches. This illustrates that "just transitions" in the sense of financially compensating negatively affected actors are perceived as one opportunity to overcome barriers and accelerate coal phase-outs. Even major coal consuming countries such as South Africa are debating just transition strategies in connection with phasing out coal (Essop, 2019; Strambo et al., 2019; Swilling et al., 2016). Additionally, countries attempt to learn from each other's experiences: Littlecott, Burrows and Killings (2018) gathered insights from the UK's coal phase-out experience to inform a decarbonization roundtable towards a coal phase-out in Chile, and Ackermann, Krynytskyi and Schön-Chanishvili (2019) collected experiences from different EU countries towards informing a Ukrainian coal phase-out strategy.

However, several questions need to be answered before concluding whether compensation schemes and "just transitions" are approaches that should be transferred across contexts, and if so how. From a justice perspective, such questions include who effectively pays for compensation schemes and who benefits from them. If taxes are allocated to different groups, are taxpayers included in decision-making? Additionally, "just transition" compensation schemes may perpetuate existing inequalities, as for instance in Canada where coal workers eligible for compensation are primarily middle-aged white men, whereas women and indigenous peoples, traditionally working in lower paying jobs that may be indirectly linked to the coal industry (such as stores and restaurants in coal mining regions) are not included in compensation schemes (Piggot et al., 2019). Another question may be how each government framing their coal phase-out policy as a "just transition" conceptualizes justice. Oei, Brauers, Herpich, et al. (2019) criticize hat most studies on coal phase-out focus on affected workers instead of environmental aspects and do not consider potential climate justice concerns. Finally, Healy and Barry (2017) argue that just transitions need to be studied more systematically with a focus on the costs they impose on governments (451).

To summarize, this sub-section showed that, while there are barriers to the expansion of global coal use and some governments announce explicit coal phase-out policies, these developments are not yet in line with limiting global climate change to 1.5° or 2°, as major coal consuming countries are not among those pledging coal phase-outs. In countries that do phase out coal, compensation schemes frequently framed as "just transition" strategies seem to play an important role. While these schemes impose additional costs on governments, they may help to accelerate phasing out coal. Assessing the costs of compensation schemes for coal phase-outs may help understand whether and at what cost it is feasible for different governments to phase out coal. The following sub-section reviews grey and academic literature on a historical regional coal decline (Appalachia region, US) and one national coal phase-out (UK). This provides relevant information as to how the decline or phase-out of the coal industry has been addressed in literature and provides initial insights regarding mechanisms and factors influencing coal phase-out pathways and their costs, which the analytical framework and methodology can build on.

2.2.2 Historical coal declines and political responses

Technological and economic developments such as the discovery of new energy technologies and changes in the costs of deploying these technologies have influenced the coal sector in the past, leading to its decline or even phase-out in several countries. This was the case, for instance, in the Appalachian region in the US, where primarily techno-economic drivers such as a decline of global coal demand, an increased consumption of natural gas within the US and price competition between coal and cheaper renewables led to the decline of the local coal industry as early as the 1960s (Baker, 2018; Bridle et al., 2017). Regulatory changes such as Obama's clean energy initiative and rising public awareness of the environmental effects of coal mining later also constituted additional drivers of the decline of the coal sector (Baker, 2018). Recovering from the decline of its primary sector was especially hard for the regional economy since the Appalachian region is structurally weak: it lacks infrastructure and connectivity to other areas, which may affect the region's appeal to new companies (Bridle et al., 2017; Caldecott et al., 2017; Del Río, 2017). It also lacks a diversified industrial sector, decreasing the availability of alternative jobs for laid off workers and increasing the dependence of the regional government on tax revenue from the coal industry (Bridle et al., 2017; Caldecott et al., 2017).

Some efforts were made to alleviate negative impacts of the coal sectors' decline on the region: The Appalachian regional commission was established in 1963 to promote regional economic development (Baker, 2018; Bridle et al., 2017). A severance tax on coal production was implemented that funded a decline of taxes on consumer goods such as food and medicine and that supported economic development activities such as infrastructure projects, public safety, environmental protection or social services (Baker, 2018; Bridle et al., 2017). These reforms were strongly opposed by the Kentucky Coal Association (Bridle et al., 2017). They were also criticized for their arguably limited success: as the severance tax was introduced when the coal industry was already in decline, the funds continuously decreased as well, and issues with distributing the money led to "taxpayers, residents and environment of Appalachia to bear the brunt of the costs" of these measures (Baker, 2018, p. 237). Baker (2018) also argues that the negative experiences and fears of the local population in the Appalachia region led them to support Donald Trump as president, who adopted a rhetoric of sympathizing with coal miners and communities and wanting to rebuild the coal sector.

In the UK, there was also significant resistance against the decline of the national coal sector, especially among miners (Bridle et al., 2017; Littlecott et al., 2018). However, observing the coal decline and final phase-out in the UK shows that, even if there is resistance among affected actors, governments do not necessarily respond through compensation schemes. The energy transition away from coal in the UK was mainly influenced by incumbents such as coal companies in the context of market-based policies and economic drivers rather than by civil society action or new entrants such as renewables companies (Geels et al., 2016). It was characterized by social conflicts and resulted in long-term unemployment and depopulation of affected coal regions (Caldecott et al., 2017).

Even though market dynamics and policies such as emission reduction targets in favour of lower carbon electricity sources led to a strong decline in coal production that was not necessarily planned by the government (Geels et al., 2016; Littlecott et al., 2018), affected actors perceived the closure of the industry as a deliberate political decision (Fothergill, 2017). One reason for this perception is the decline of the mining industry in the South Wales region, which began in the 1980s due to increasing environmental legislation and the discovery of alternative and equally affordable energy sources such as oil under the North Sea (Bridle et al., 2017). Initial resistance against the decline was limited as alternative jobs were available, but as this availability decreased, opposition among miners grew (Bridle et al., 2017). This led to strikes in the 1970s and 1980s, which had a visible effect on the share of coal in the electricity mix, even endangering the security of supply momentarily (Littlecott et al., 2018). Withstanding this opposition and to counter the influence of miners on the security of supply, the Conservative government which did not rely on votes from coal miners launched a program of mine closures in the 1980s (Bridle et al., 2017; Littlecott et al., 2018). Coal was replaced through a dash for gas as the electricity sector became privatized and liberalized throughout the 1990s (Fothergill, 2017; Geels et al., 2016).

For a while, gas was more competitive than coal until wholesale gas prices rose again in the early 2000s, leading to investment in CCS to explore the opportunities for cleaner coal production (Littlecott et al., 2018). However, this technology did not materialize, among others due to public opposition and a drop in energy demand and less available funding due to the financial crisis in 2008 (Geels et al., 2016; Littlecott et al., 2018). These factors, together with increasing carbon prices and other emission reduction regulations on national and EU level led to three waves of closures of coal power plants from the early 2000s until 2018, and the announcement of a national coal phase-out in 2015 (Littlecott et al., 2018). Even though there was never a deliberate, coherent just transition or compensation strategy for negatively affected actors in coal regions, over time several ad-hoc policies were implemented. These policies included financial support for former mining communities, laid-off workers of power plants and mines, compensation of consumers for higher electricity prices and support for coal corporations for instance through lower taxes (Bridle et al., 2017; Fothergill, 2017). The ad-hoc nature of these policies has arguably negatively affected their success, especially in mining areas that were structurally weak and where the share of coal jobs was comparatively high (Fothergill, 2017).

Both examples of coal declines and the responses of affected actors provide interesting insights into various factors and mechanisms that may influence coal phase-out pathways. Depending on the context of phasing out coal in different countries, for instance the interests and political power of affected actors and the established structures that enable different actors to influence political processes, the decline of the coal industry may invoke stronger or weaker resistance. In Appalachia and the UK, governments made attempts to compensate affected actors, but the success of these compensation schemes seems to have been limited in both cases.

While this shows that negative effects of coal sector decline on coal regions and workers may influence government action, there is a limit to which the findings from past phase-outs can help understand the feasibility of necessary climate action. Coal phase-outs or declines in the past have often not occurred primarily as a result of climate policy, but due to other socio-economic drivers (Caldecott et al., 2017). Affected actors may have had more awareness of reasons for the phase-out which may have limited their resistance, even though they faced negative consequences. Governments were also not always able to plan transitions ahead as they may have been surprised by techno-economic developments, which influenced the setup of compensation schemes and other complementary policies (Caldecott et al., 2017). Finally, energy transitions can take a long time (e.g. in the UK, see Fothergill, 2017), giving affected actors possibilities to adjust to changing circumstances. In light of the urgency of reducing emissions, it is however necessary to phase out coal as soon as possible. This means that climate-based coal phase-out schemes may face higher resistance from affected actors that may not agree with the need to reduce emissions and to do so as soon as possible, which may increase some costs such as stranded assets and foregone profits.

2.3 Conclusion: Political feasibility and costs of phasing out coal

This literature review highlighted that phasing out coal-fired electricity is an essential and urgent measure to achieve timely decarbonization (IPCC, 2018). However, as with other climate mitigation measures, it is not evident whether phasing out coal in time will be feasible. The two previous sub-sections have shown that economic, social and political drivers, including climate regulations, may lead to phase-out or decline of coal industries. Compensating affected actors of coal phase-outs is a common approach adopted by different governments to address negative effects of phasing out coal on different societal groups. Current coal phase-out policies adopted to reach necessary emission reductions to limit global climate change are often combined with compensation schemes framed as "just transition" strategies. These compensation schemes often target coal mining companies and coal power plant owners, laid-off workers and structurally weak (former) coal communities to support their further economic development. Such "just transition" strategies are implemented to enable the phase-out of coal in an (arguably) just, equitable and socially acceptable manner, even though this may be questioned based on how different actors conceptualize justice. From an emission mitigation perspective, "just transition" approaches may also help to accelerate coal phase-outs by alleviating negative effects on affected actors and thus decreasing their resistance against political action to phase-out coal.

As Jewell and Cherp (2020) argue, assessing the costs of observed climate action and the financial capacities of relevant actors that implement this climate action to bear these costs can help to understand the feasibility of decarbonization. As the literature review has shown, the costs of coal phase-out policies and complementary compensation schemes have not yet been assessed (Healy & Barry, 2017). This thesis thus sets out to quantify the costs to governments of accelerating coal phase-outs through compensation schemes. The aim is to contribute to literature on the political feasibility of limiting global climate change to 1.5°, for which phasing out coal is essential. As there has not yet been a systematic assessment of the compensation costs of phasing out coal, this thesis develops a conceptual framework answering three RQs as elaborated in the following section.

3 Framework and methodology

3.1 Conceptual framework and research design

The conceptual framework enables this thesis to advance understanding of the feasibility of phasing out coal by calculating its compensation costs. As there are many ways to conceptualize the cost of climate policies (as shown in section 2.1.3), section 3.1.1.1 outlines the difference between aggregate and distributional costs of climate mitigation. It also explains how distributional costs and government compensation affect the political feasibility of coal phase-outs. Section 3.1.1.2 explains how the latter can be approximated by the compensation costs paid by governments to affected actors and how this thesis analyzes compensation costs building on the concept of MAC. This gives rise to the RQs and the research design, which are described in section 3.1.2.

3.1.1 Costs and political feasibility of climate change mitigation

3.1.1.1 Aggregate and distributional costs

As discussed in the literature review, decarbonization pathways require the implementation of several climate mitigation measures. To help decision makers prioritize which ones to implement first, climate mitigation measures have for instance been ranked according to their marginal abatement cost (MAC): cost of abating a unit of emissions. MAC does not consider how these aggregate costs are distributed among different societal groups. As shown for instance by Fullerton (2011, 2017), depending on the measure, some societal groups may lose, while others benefit. Costs measured by MAC such as LCOE may be paid for by utilities that need to install new technologies, by energy consumers if utilities raise electricity prices, or by governments if they subsidize the instalment of new technologies. This means that, even though a climate mitigation measure might have overall negative or very low MAC, costs and benefits of these measures may be disproportionally distributed across societal groups.

Often, groups that are already worse off, for instance lower income groups, are more negatively affected by climate policies as they may spend a higher share of their disposable income on goods that may become scarce or more expensive through climate mitigation policies (Markkanen & Anger-Kraavi, 2019). One recent example is the carbon tax in France. An increase in the carbon tax was strongly opposed due to its (perceived) distributional effects as people were “concerned that the carbon tax may penalize rural and peri-urban households”, leading to strong protests and resistance, eventually halting the planned measure (Douenne & Fabre, 2020). This demonstrates how distributional costs may affect feasibility of climate mitigation measures. If certain groups perceive the costs imposed on them too high, they may resist to the extent that a measure cannot be implemented.

On the global level, studies address distributional costs of climate mitigation through the concept of burden sharing (Höhne et al., 2014; Leimbach & Giannousakis, 2019; van den Berg et al., 2019), as discussed in the literature review. Burden sharing aims to make emission mitigation fairer. It can be achieved through applying equity principles when developing climate mitigation pathways to equitably distribute costs and benefits of climate mitigation. Another possibility is financial transfers from rich to poor countries, compensating poor countries for negative distributional effects of climate change mitigation. Financial compensation may also be applied by governments to compensate negatively affected actors of climate policies within the national level. As shown in the literature review, governments start to adopt “just transition” schemes to compensate actors negatively affected by coal phase-out policies. The term “just transition” indicates an ideological “justice” dimension to these strategies, similar to the concept of burden sharing: they may aim to more fairly and equitably distribute the costs and benefits of low-carbon transitions among affected actors. Such redistribution may also serve an instrumental purpose through limiting resistance against climate policies if it reduces negatively affected actors' costs.

However, financial compensation may also decrease the political feasibility of phasing out coal. As Jewell and Cherp (2020) argue, relevant actors must be able to bear the costs of specific climate mitigation measures. This applies for instance to national governments' ability to pay for compensation costs associated with phasing out coal. This echoes Leimbach and Giannousakis' (2019) understanding of the political feasibility of global decarbonization pathways, based on "requirements of climate finance across regions" to offset distributional costs. Compensating affected actors requires financial and institutional capacity of governments. In other words, they need to be able to afford spending part of their government budget on compensating affected actors. While some governments may have this capacity, others may not be able to afford compensation schemes.

3.1.1.2 Compensation costs

While compensation schemes impose costs on governments as outlined above, they do not necessarily increase the aggregate cost of emission mitigation to society. Instead, they redistribute the costs of emission mitigation across different societal groups: governments generate revenue, for instance by collecting taxes from citizens and companies. Through transfer payments, they can reallocate part of this money to different societal groups (Posner, 2003). In the case of coal phase-outs, for instance, they may redistribute money to workers and companies in the coal sector, coal-dependent regions, or electricity consumers. How costs are redistributed across different societal groups may depend on whether the aim of this compensation is to make the transition more equitable, or whether payments are instrumental to reduce resistance against phasing out coal. The amount of compensation paid may even differ among countries who aim to increase fairness of phasing out coal, depending on their understanding of "fairness" or "justice", and how this is implemented in the policy scheme, similarly to how different implementations of burden sharing may compensate different countries to different extents (Leimbach & Giannousakis, 2019; van den Berg et al., 2019).

Compensation costs do not directly capture distributional costs to all societal groups: some groups may be powerful enough to demand compensation that surpasses their incurred costs, whereas other groups may not be compensated to the full extent by governments. Nevertheless, compensation costs may serve as a proxy of distributional costs, as they indicate the size of government transfers that are necessary to redistribute costs across societal groups and thus enhance the fairness of and decrease resistance against coal phase-out policies. Thus, approximating distributional costs is relevant as it advances our understanding of the political feasibility of climate mitigation: the larger the disproportionally distributional effects, the larger the required compensation payments by governments, which in turn requires financial and institutional capacity.

This thesis borrows from the traditional MAC concept and calculates compensation costs per avoided ton of emissions of the respective coal phase-out. This makes it possible to better compare compensation costs across different contexts, and to begin to understand which context-dependent factors lead to higher or lower compensation costs per avoided unit of emissions of phasing out coal. This may also be helpful if, in the future, compensation costs per avoided unit of emissions are known for several climate mitigation measures: Comparing distributional costs of emission mitigation measures may provide a new way of ranking these measures, according to the necessary extent of redistribution of costs by governments. The lower the distributional cost, i.e. the more initially fair the measure, the less government capacity is necessary to redistribute costs which may increase the political feasibility of the measure.

3.1.2 Research questions and research design

Based on the conceptual framework outlined above, this thesis assesses compensation costs of coal phase-out policies as a proxy of the distributional cost of phasing out coal. This thesis thus first identifies observed cases of coal phase-out policies at the national level. These cases are analyzed using a "structured, focused comparison" methodology, which includes "the use of a well-defined set of theoretical questions […] to structure an empirical inquiry on a particular analytically defined aspect of a set of events" (Cherp et al., 2017; Levy, 2008). The "set of events" are the selected national governments. The "analytically defined aspect" to be researched is the compensation cost of CO_2 emissions abatement through coal phase-outs in these countries. The "well-defined set of theoretical questions" are the RQs which are systematically applied to each country:

1. What are the avoided emissions of the coal phase-out pledges?
2. How high are compensation costs of the coal phase-outs?
3. How are compensation costs allocated among different actors and purposes?

RQ 1 and RQ 2 serve to identify necessary data to calculate compensation cost per avoided ton of CO_2 emissions, similar to the traditional MAC approach. It is to be expected that compensation costs per ton of avoided emissions will differ across the observed cases. RQ3 serves to break up the aggregate estimates depending on who benefits from compensation schemes (allocated among actors) and what the pledged compensation is meant to be spent on (allocated among purposes). Purposes may include retirement aid for workers, renaturation of mining areas or support for coal-dependent regions.

In addition to answering the RQs, this thesis provides background information for each country to enable readers to understand the context and how it may influence the results, as costs of climate mitigation measures and capacities of relevant actors are context-dependent (Jewell & Cherp, 2020).

The results of individual countries will be compared against each other and against the MAC of other emission mitigation policies to better understand costs and necessary financial capacity of phasing out coal in different contexts and how this may compare to other emission mitigation measures necessary for decarbonization.

3.2 Methodology

3.2.1 Case study selection

This thesis compares coal phase-out policies and compensation costs of six countries. Countries were selected on the basis that they fulfill two conditions:

- the government expressed a commitment to phasing out coal, for instance through a law, policy document, or through an official pledge documented by the PPCA,
- and that there is government commitment to financially compensate affected actors, for instance through a law, policy document or expressed in other government communication such as press releases.

They were chosen out of current PPCA members with installed or planned coal capacity, as indicated in the left column of Table 3-1, and countries whose governments announced coal phase-outs to the knowledge of the author (for instance at the UN Climate Summit) but did not join the PPCA: Chile, Czech Republic, Hungary, Spain and South Africa reportedly announced coal phase-outs or just transition strategies in relation to phasing out coal (Azzopardi, 2019; Baratti, 2019; Bronte, 2019; H. E. Evans, 2019; Joubert, 2019; Strambo et al., 2019; Tsagas, 2019). PPCA members without installed or planned coal capacity (indicated in the right column of Table 3-1) were not considered as possible case studies.

Table 3-1 PPCA members

Members with installed/planned coal power	**Members without installed/planned coal power**
Austria	Angola
Canada	Belgium
Denmark	Costa Rica
Finland	El Salvador
France	Ethiopia
Germany	Fiji
Greece	Latvia
Ireland	Liechtenstein
Israel	Lithuania
Italy	Luxembourg
Mexico	Marshall Islands
Netherlands	Niue
New Zealand	Switzerland
Portugal	Tuvalu
Senegal	Vanuatu
Slovakia	
Sweden	
UK	

Source: (Global Energy Monitor, 2020)

Out of this total pool of countries, case studies were identified through a systematic Google search. The same search terms were applied to each possible country:

- *country name* + coal + phase out
- *country name* + coal + just transition
- *country name* + coal + compensation

The term coal phase out was chosen to assess whether there is a phase-out pledge from the respective government. The terms just transition and compensation were chosen to assess whether there are any financial compensation schemes to affected actors. The two terms were combined as some governments frame these compensation schemes as "just transition" policies, whereas others may not do so, or only include part of the total compensation within just transition schemes. Combining both search terms thus meant to include countries with compensation schemes other than framed just transitions as well. Usually, the results on the first five google pages were reviewed, except in cases where results did not extend to five pages. Wikipedia pages were excluded from the reviewed documents, as were documents that did not relate to the current coal phase-out in the given country. All other types of results, such as online blog posts, newspaper articles, press releases from utilities, governments or non-governmental organizations (NGOs), were reviewed for evidence that governments committed to phasing out coal and compensate affected actors.

Table 3-2 Case-study countries and phase-out dates

Country	Phase-out date
Slovakia	2023
Greece	2028
Finland	2029
Spain	2030
Canada	2030
Germany	2035/2038

Sources: (Entwurf Kohleausstiegsgesetz, 2020; Canadian Environmental Protection Act, 1999; Ministerio para la transición ecológica, 2020; Ministry of Economic Affairs and Employment, 2019a; Ministry of Economy, 2019; Ministry of Environment and Energy, 2019b).

This systematic assessment led to the choice of the six countries summarized in Table 3-3. Spain was included even though it is not a PPCA member and there is not currently, nor seems to be a plan to implement, an official policy to phase-out coal in electricity generation. However, the Spanish government has announced that it assumes that economic drivers are strong enough to lead to a coal phase-out by 2030 latest and has included this assumption in its latest NECP. The Spanish government has also shown commitment to implementing compensation schemes throughout this transition (see further explanations in section 4.4.1).

3.2.2 Case analysis

RQ1: What are avoided emissions of the coal phase-out pledges?

Avoided emissions of the coal phase-outs are individually calculated for each country according to the methodology applied by Jewell et al. (2019) and with the help of Dr. Vadim Vinichenko. Power plant data for each country is retrieved from the World Electric Power Plant Database from S&P Global Platts. The average retirement age of power plants for each country is calculated as a mean across all retired power plants in this country since 2000. This average retirement age is the expected retirement age of all power plants that operate in 2019. In the business as usual (BAU) scenario, coal plants are assumed to retire at this expected retirement age, and it is assumed that no additional power plants are built. In the phase-out scenario, power plants are retired latest in the phase-out year in addition to BAU retirement to estimate the additional effect of the coal phase-out policy. The difference between expected and phase-out retirement age determines avoided energy generation due to the phase-out, based on the average national load factor for 2007-2016 for each individual country. To estimate emissions of avoided electricity generation, we apply technology-specific efficiencies to the power output of each plant to assume coal consumption. We then apply emission rates for the thermal content of different coal types to estimate avoided emissions. For a more detailed description of the methodology, please refer to Jewell et al. (2019) (Methods section).

RQ2: How high are compensation costs of the coal phase-outs?

This RQ quantifies money that national governments pledge to compensate affected actors of coal phase-out policies. Data is retrieved from official government documents such as policies, press releases or plans.

As there are significant differences between uncertainties of different pledges within countries, a lower and an upper boundary are calculated for each country. The lower boundary includes money assigned to specific actors and/or purposes in coal phase-out plans and regulations. It also includes money linked to the coal phase-out in government budgets or official press releases. The upper boundary additionally includes money earmarked for future agreements, but which has not been allocated to specific beneficiaries or purposes (this occurs in Greece, Spain and Slovakia).

The coal mining industry and power generation from coal are closely connected, as coal mining provides the fuel for power generation. Insofar as domestic coal production is used for domestic power generation from coal, a coal power phase-out leads to a phase-out of coal mining as well. This means that affected actors of coal mine closures may need to be compensated in the course of a coal phase-out. However, if domestically produced coal is exported or used for metallurgical purposes, a coal power phase-out may not affect coal mining. This thesis considers compensation for coal mine closures in the upper boundary cost estimates of coal phase-outs to account for this possible connection.

The Slovakian and German governments also currently pay money for past mine closures, which is included in the upper boundary. Even though this is not necessarily the cost of the current phase-out, it must be paid in parallel to current costs. The upper boundary also includes money payed for phasing out coal by regional governments, which is applicable to the Albertan regional government in Canada. It is included as this constitutes part of the total compensation cost of phasing out coal in Canada. Additionally, the upper boundary includes money pledged to support coal phase-outs in other countries, also applicably to Canada. Even though this does not constitute national costs of phasing out coal, it might be indicative of how one government's capacity may support phasing out coal in other countries where government capacities may be lower.

Considering the time value of money, the pledged amounts are discounted to the US dollar (USD) value in 2018. To assume the time value of money of government pledges, this thesis relies on rules given within government documents. If rules are not specified, the date at which the money is planned to be paid out will be used, if this is known. If a range of years is given over which a certain amount is to be paid out, it is assumed that money will be paid in equal tranches annually. If the year(s) in which the money is to be payed is not known, or there are no inflation rate estimates for the planned year, the time value of money is assumed to be at the date of the phase-out pledge. Inflation rate estimates (average consumer prices, annual percentage change), are retrieved from the IMF datamapper (IMF, 2020). Data for inflation in all six countries (estimates up to 2024) were downloaded on 14.4.2020. They were applied to the relevant compensation pledges, discounting these to Canadian dollar (CAD) or Euro in 2018.

To make the results comparable, the average exchange rate of CAD or Euro to USD in 2018 was applied to the results. The official exchange rates (LCU per USD, period average) were retrieved from the World Bank Database on 16.4.2020. The exchange rate from CAD to USD was 1.296 (IMF & International Financial Statistics, 2020a) and 0.847 from Euro to USD (IMF & International Financial Statistics, 2020b).

Drawing from the MAC concept, estimated compensation costs are divided by estimated avoided emissions. Additionally, to compare data across several parameters, total costs are also divided by the number of years over which they are to be paid. This is usually assumed to start from the year of the coal phase-out pledge and end in the year of the coal phase-out. The total costs are also divided by the number of workers directly employed in the coal sector in each country.

These quantitative results are followed by a discussion of estimated effects of international finance, double counting of projects and co-benefits of phasing out coal and compensating affected actors. Even though this was beyond the scope of this MSc thesis, future research may aim to quantify these factors and thus better understand coal phase-out costs.

RQ3: How are compensation costs allocated among different actors and purposes?
Finally, phase-out and compensation policies, plans and announcements are analyzed to find out which actors are compensated in different countries and for what purposes compensation is pledged. This may help to understand which types of costs and which actors drove demand for compensation in different countries.

3.2.3 Data collection

Data collection is undergone separately for each case:

1. Data on the coal phase-out date and pledged financial compensation for each case is retrieved from official government documents such as national legislation where available, alternatively National Energy and Climate Plans (NECPs) submitted by each European Union (EU) member state to the European commission, or official records of government pledges on the PPCA website, planning documents of governments or appointed bodies such as just transition commissions, or governmental press releases. Coal mining subsidies also need to be granted by the EU Commission to EU member states. EU state aid cases thus provide an additional source detailing amounts, timelines and beneficiaries of national support for national coal mining phase-outs.
2. To complement government-based information, this thesis also draws on existing modelling studies from think tanks or other research institutes that quantified avoided emissions or costs of phasing out coal where available. These studies may have applied different methodologies and considering their results thus helps to estimate possible margins of error.
3. Data on inflation and exchange rates are retrieved from the World Bank and IMF online databases that are referenced above.
4. Data to calculate avoided emissions is retrieved from the Platts database.
5. Estimates of co-benefits of phasing out coal such as health and environmental costs is retrieved from different modelling studies, some of which were conducted by government agencies, whereas others stem from independent think tanks, research organizations or from interest groups such as NGOs. Data on the potential availability of international finance are retrieved from the European Commission and from previous research.
6. The background section for each case includes information on the national energy system, the political system and the development of the role of coal in the electricity system over time. This is retrieved from documents that came up during the Google search for case selection and from research articles retrieved from CEU's and Lund University's online libraries through the search terms: *country name* + coal + transition.
7. The background section also summarizes information that existing literature, specifically (Jewell, 2011; Jewell et al., 2019) have used as indicators of the costs of phasing out coal and the capacities of relevant actors: share of coal in electricity supply, installed GW coal capacity, number of workers in coal sector, domestically produced coal and coal dependence coal mining to assess the size and strength of coal sector in country. Coal dependence expresses how much coal a country produces compared to how much it uses for electricity generation using data from Jewell et al. (2019). If a country is a net exporter of coal, its coal dependence (dependence on imported coal) may be 0 even if it imports some coal for electricity generation. To understand the government's capacity to bear these costs and implement a coal phase-out, the thesis documents GDP/capita and the Functioning of Governance (FoG) index. FoG is indicated for the year in which each country committed to phasing out coal as recorded through national commitments (Finland), joining the PPCA (Canada, Slovakia, Germany, Greece) or documenting in the National Energy and Climate Plan (NECP) the expected share of coal in the national energy system at 0% by 2030 (Spain).

4 Analysis and results

This chapter contains detailed analysis on the six case-study countries, including background information on the development of each country's coal sector over time, the decision-making process towards the coal phase-out and the content and setup of the compensation schemes for the interested reader. The following chapter 5 contains a comparative summary presentation of these results.

4.1 Slovakia

4.1.1 Background information

Table 4-1 Background information Slovakia

Capacity-related indicators		**Cost-related indicators**	
Functioning of government	9/12	Share of coal in electricity supply	11%
GDP/capita (USD)	19,500	Installed MW coal capacity	690
GDP (USD bln)	110	Domestic coal production (ktoe)	370
		Coal dependence	86%
		Nr of workers in coal sector	2700

Sources: (FreedomHouse, 2020; Global Energy Monitor, 2020; IEA, 2020f; Jewell et al., 2019; Vazquez-Hernandez et al., 2018; World Bank, 2020k, 2020e), coal capacity from Jan 2020, FoG from 2019, all other data from 2018. Data at 10% accuracy. For precise values see Appendix 1.1

4.1.1.1 The Slovakian energy system and coal sector

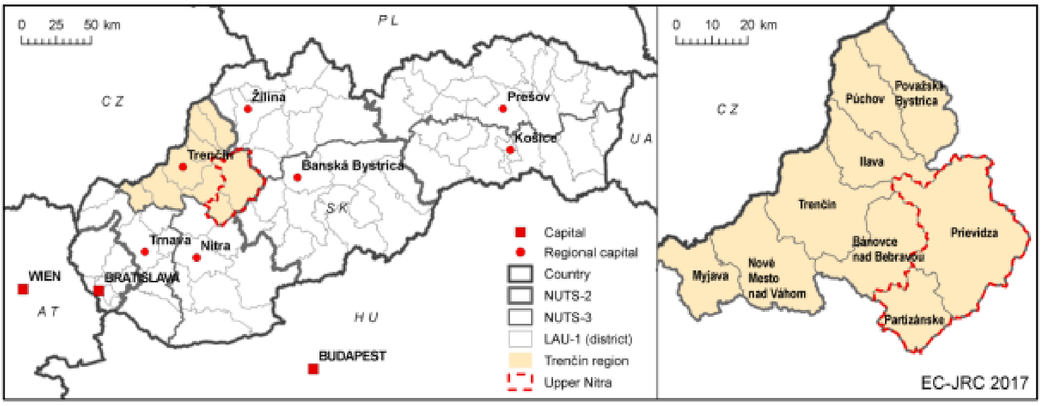
In Slovakia, coal is mainly used for electricity and heat production as well as in the steel sector (Filcak et al., 2018; Oravcová, 2019; Popp, 2019). The industrial sector accounts for 40% of total final energy consumption (Filcak et al., 2018; IEA, 2018b). Currently, the largest electricity source is nuclear which supplied almost 60% of electricity in 2018 (IEA, 2020f). Four nuclear reactors are currently in use and two NPPS are under construction, further decreasing the dependence on coal in the electricity system (Filcak et al., 2018; Oravcová, 2019). Among all IEA members, Slovakia has the eighth-lowest share of fossil fuels in its total primary energy supply (TPES), and the third-highest share of nuclear power (IEA, 2018b). There is some use of renewables, especially of hydro and biofuels, with little but growing shares of solar and wind (IEA, 2018b, 2020f; Oravcová, 2019). While electricity generation is dominated by low-carbon sources, fossil fuels provide most heat in Slovakia: natural gas and coal together account for 60% of total district heating, with an increasing share of biomass (IEA, 2018b).

Coal use continuously decreased since 1978, when it supplied more than 60% of TPES (IEA, 2018b). Domestically produced lignite was the main coal source until the late 1990s, before imported overtook domestically produced coal (IEA, 2020f). In 2007, about 4mln tons of lignite were produced, which decreased to 1,8 mln tons in 2017 (Popp, 2019). The productivity of the Slovakian mining company declined by 19% from 2010 to 2017 (Filcak et al., 2018). One reason is that lignite mined in Slovakia is of lower quality and more expensive than in other countries (Oravcová, 2019; Popp, 2019). Coal is imported from the Czech Republic (lignite), Ukraine (hard coal), Russia and Poland (Donnari et al., 2018; IEA, 2018b). Consumption of both domestic and imported coal decreased continuously since 1990 (Donnari et al., 2018; IEA, 2020f).

Two power plants currently produce electricity and heat from coal: Novaky and Vojany, which each operate two coal-burning blocks (Ministry of Economy, 2019). Novaky, a combined heat and power (CHP) plant is the major source of electricity in the Trencin region where it also supplies district heating (Donnari et al., 2018). While both power plants produce electricity from both biomass and coal, Novaky uses domestically produced lignite and Vojany imported hard coal (Jancarikova & Hudson, 2018; Slovenské elektrárne, 2019). Both plants are owned by Slovenské Elektrárne, a utility that is in turn co—owned by the Slovak state, Italy's Enel and the Czech energy group EPH (Energetický a průmyslový holding) (Jancarikova & Hudson, 2018; Slovenské elektrárne, 2019). Since 2016, lignite is mined by one company, Hornonitrianke Bane Prievidza (HBP) (Donnari et al., 2018; IEA, 2018b; Jancarikova & Hudson, 2018). Slovenské Elektrárne purchases almost 94% of coal produced by HBP (Donnari et al., 2018).

The energy policy 2014 foresaw the use of coal until 2035 (IEA, 2018b; Ministry of Economy, 2014). However, both lignite mining and power generation from coal require financial support. Due to its comparatively low quality and high cost, domestic lignite mining has been dependent on state subsidies for decades (Filcak et al., 2018). This subsidy was payed to electricity producers using domestic coal and financed through increasing electricity prices, estimated to cost electricity consumers between €53 mln and €100 mln per year (Donnari et al., 2018; IEA, 2018b). This may be one reason for the decreasing popularity of coal subsidies among the public, experts and among both coalition and opposition parties in government (Filcak et al., 2018). Subsidies were long justified with the fact that domestic coal supply was essential for the security of supply, an argument which may lose its base through the deployment of additional NPPs (IEA, 2018b). Further extending the life of the Novaky plant and ensuring that it complies with new emission standards would also require substantial investments, estimated at around €90mln (Donnari et al., 2018; Filcak et al., 2018; Jancarikova & Hudson, 2018).

4.1.1.2 Slovakia's coal region: Upper Nitra



Location of Trenčín region (left) and Upper Nitra and the districts of Trenčín region (right)

Figure 4-1 Slovakian coal regions

Source: (Donnari et al., 2018, p. 6)

The importance of domestically produced coal declined as nuclear power and biomass became increasingly used (IEA, 2018b). Coal mining is still of relative importance in the Horna Nitra region, which is the main lignite basin of the country and where coal production provides an important part of the local economy (Popp, 2019). Almost all jobs created through the coal mining industry, estimated between 700 and 3260, almost all of them are situated in the Horna Nitra region (Popp, 2019; Vazquez-Hernandez et al., 2018). HBP and its daughter company HBz are among the largest employers in this region (Filcak et al., 2018). Horna Nitra is also one of three pilot regions of the EU Platform for Coal Regions in Transition which provides technical support for regional transitions away from coal (Popp, 2019). Horna Nitra is divided in two self-governing regions, Trencin and Nitra. Most mining operations are located in the Prievidza district situated in Trencin (see Figure 4-1) (Filcak et al., 2018).

Even though the economy of Prievidza was highly dependent on coal mining in the past, it started to diversify in the 2000s, with growth in other industrial sectors such as the automotive sector, machinery or plastic production while HBP's productivity declined (Filcak et al., 2018). The industrial sector overall supplies almost 50% of jobs in the region (Donnari et al., 2018; Popp, 2019). In response to economic diversification and the presence of new international companies and investors, regional GDP has grown and the unemployment rate has decreased: in both Prievidza and Partizanske unemployment is now lower than on average in Slovakia (Donnari et al., 2018, 2018; Filcak et al., 2018; Popp, 2019). The region's development was supported both through national finance and investments of the European Structural and Investment Fund (ESIF) (Filcak et al., 2018). Regional economic diversification may reduce the reliance on the coal sector for employment and thus constitute an enabling factor for transitioning away from coal.

Another enabling factor may be the age structure among miners. The largest age group of miners are above 55 years old (24.51%), and almost two-thirds (62.67%) are above 45 years old, which means that they approach retirement soon and do not depend on finding new employment for an extended period of time (Filcak et al., 2018). However, this age structure is indicative of the general aging population of the Horna Nitra region, which is more pronounced than in the rest of the country (Donnari et al., 2018; Filcak et al., 2018). The region's population has declined since the late 1990s, caused by both a negative migration balance and a natural population decline due to the age structure (Donnari et al., 2018). The region also faces other structural problems such as a lack of transportation and economic infrastructure: Prievidza is located apart from internationally well-connected railway routes, and no highway has been built in the region (Filcak et al., 2018). Another issue is that many available jobs do not fit the educational profile of newly registered job seekers: The largest proportion of job seekers has obtained basic education whereas many vacancies seek higher qualified employees (Donnari et al., 2018). Even the mining sector had difficulties hiring employees as lignite mining is not perceived as a desirable employment (Donnari et al., 2018). Aiming to respond to these challenges, the development of an action plan for the post-coal future and further structural development of the region was initiated by locals and further developed on national level (Catu, et al., 2018; Ilciková, 2019; Popp, 2019; PPCA, 2019a).

4.1.1.3 Coal phase-out policy

The Slovakian environment minister had declared 2023 as the coal phase-out year in 2017, including both coal mining and electricity generation from coal (Galgóczi, 2019). However, the prime minister at the time supported the lignite mining industry (Szalai, 2017). In 2019, a new government under president Zuzana Caputova, who is known to prioritize climate issues, was elected (Oravcová, 2019). Similarly, in local elections in 2018, candidates elect in the Horna Nitra region supported plans to phase out coal (Ilciková, 2019). The prime minister and president jointly declared 2023 as the official phase-out date for coal in electricity generation and joined the PPCA in 2019 (PPCA, 2019a). Subsidies for uneconomic coal mines in accordance with EU regulations are also envisioned to end in 2023 (Jancarikova & Hudson, 2018; Popp, 2019). 2023 may be a convenient year as, as mentioned above, the Novaky power plant approaches the end of its useful life and would require significant investments to operate further. Some suggest that one coal mine outside the Horna Nitra region may remain open to supply lignite for purposes other than electricity generation (Ilciková, 2019).

The coal phase-out seems to be based primarily on market-based policies as the environmental strategy 2030 suggests: "mechanisms resulting from the revised emissions trading directive and other mechanisms will be used" (Ministry of Environment, 2019, p. 33). However, the coal phase-out policy in the final NECP is described as both a regulatory and economic measure (Ministry of Economy, 2019). The NECP (Ministry of Economy, 2019) clarifies that Vojany "is being considered for transformation into a facility to use secondary fuels" (p. 86), which might refer to biomass. Electricity generation at Novaky is to be terminated, but heat production to be continued as its "fuel base" is transformed (p. 85). While this suggests a complete phase-out of coal in electricity generation, it seems that coal will continue to be relevant for heat generation. Even though the NECP foresees "reducing the share of coal in heating to the benefit of renewables" (p. 11), the expected share of coal in 2030 is significant:

Table 4-2 Real and projected energy mix with heat from district systems (GWh)

Primary fuels	**2010**	**2012**	**2014**	**2015**	**2017**	**2019**	**2021**	**2023**	**2025**
Natural gas	12,551	11,001	8,361	9,875	9,686	9,285	9,497	9,983	10,479
Coal	**5,519**	**3,177**	**3,177**	**3,230**	**3,221**	**3,157**	**3,095**	**3,033**	**2,973**
Wood	1,293	2,643	2,643	3,059	3,183	3,311	3,378	3,446	3,515
Nuclear	1,526	1,373	1,373	996	1,037	1,078	1,089	1,111	1,133
Other fuel	3,112	3,895	3,895	3,704	3,663	3,622	3,611	2,589	3,567
Total	*24,002*	*22,089*	*19,063*	*20,864*	*20,790*	*20,453*	*20,669*	*21,162*	*21,666*

Source: Adapted by author from Ministry of Economy, 2019, p. 185

Phasing out coal mining and ending electricity generation at the Novaky plant is implemented in line with the Action Plan for the Transformation of Upper Nitra. The plan was kicked off through a local initiative and subsequently institutionalized and placed in the responsibility of the Deputy Prime Minister's Office (PMO) in April 2018 (Catu, et al., 2018; Ilciková, 2019). The PMO established a Working Group for the Preparation and Implementation of the Upper Nitra Transformation Action Plan (Ilciková, 2019; PMO, 2019). This working group included representatives of the PMO, relevant ministries, local authorities and governments of the Upper Nitra region, civil society and the private sector (Ilciková, 2019; Ministry of Economy, 2019; PMO, 2019). The final plan was established with technical support financed through the EU Platform for Coal Regions in Transition (Donnari et al., 2018; Ilciková, 2019): PricewaterhouseCoopers (PwC) was tasked with overseeing the creation of the report and examining possibilities for funding of potential projects (Ilciková, 2019). Their work included meetings with local stakeholders and study visits to coal regions in Germany and the Czech Republic (PMO, 2019; Seban, 2019).

4.1.2 Compensation cost of Slovakian coal phase-out

4.1.2.1 RQ1: What are the avoided emissions of the coal phase-out?

Avoided emissions of the Slovakian coal phase-out pledge are estimated at 8.4 MtCO_2 emissions over five years, from 2019 to 2023. Total annual CO_2 emissions in 2018 accumulated to 32Mt (IEA, 2020f). This means that on average, annual avoided CO_2 emissions due to the coal phase-out amount to 5.3% of total CO_2 emissions in 2018.

4.1.2.2 RQ2: How high are the compensation costs of the coal phase-out?

Total costs are estimated between $75.9mln and $2,561mln. The lower boundary includes one payment of $75.9mln pledged to HBP, to be payed from 2019-2027 (State Aid SA.55038 (2019/N), 2019). The upper boundary adds payments that were pledged before the current coal phase-out but that are still ongoing and thus additionally stretch the government's budget, contributing to the cost of phasing out coal: $5.1mln to HBP for the phase-out of the Cigel mine, envisioned to end in 2020 (State Aid SA.39096 (2014/N), 2014; Ministry of Economy, 2019). The upper boundary also considers money that is earmarked for future payments but has not been specified in laws or government budgets yet: an announced $2,474.9 mln (€3bln) fund which is envisioned to draw on international and national finance (PPCA, 2019a; Seban, 2019). Even though it is unlikely that the total amount will be payed toward the coal transition of the Upper Nitra region, especially considering the current COVID-19 crisis and its effect on public spending, this amount is included here as a possible upper limit. It also visualizes the potential effect that the availability of international finance can have on the costs of phasing out coal.

Table 4-3 Total and relative costs, upper and lower boundaries

Type of cost	Lower boundary	Upper boundary
Total	$76mln	$2,600mln
Total/avoided $MtCO_2$	$9mln	$300mln
Total/worker	$0.03mln	$1mln
Total/year	$15mln	$500mln

Sources: Cost/worker considers direct employees of both coal mines (2200) and coal plants (500) (Vazquez-Hernandez et al.,2018). Cost/year is calculated over five years as the phase-out was announced in 2019 and is expected to end in 2023 (PPCA, 2019a). Data at 10% accuracy.

4.1.2.3 RQ3: How are compensation costs allocated among actors and purposes?

Payments to HBP are dedicated to several different purposes: first, to workers who lost their jobs or will lose their jobs due to the coal phase-out, for instance as early retirement payments (State Aid SA.39096 (2014/N), 2014; State Aid SA.55038 (2019/N), 2019). Second, money is allocated for additional underground safety work which needs to be performed as mines close early, as well as for the reclamation and re-cultivation of former coal mines (State Aid SA.39096 (2014/N), 2014; State Aid SA.55038 (2019/N), 2019). Finally, part of the money is dedicated to HBP itself (State Aid SA.55038 (2019/N), 2019), likely to compensate for foregone profits.

Money earmarked for the implementation of the Transformation Action Plan will be spent on different projects and allocated to different beneficiaries in line with the four main pillars of the plan: (1) Mobility and interconnection, (2) Economy, entrepreneurship and innovation, (3) Sustainable environment and (4) Quality of life and social infrastructure (Seban, 2019). This includes, among others, development of roads and rail infrastructure, further diversification of the local economy through supporting small and medium businesses, supporting low-carbon energy sources and developing cultural and recreational opportunities in the region (Seban, 2019). Some criticize the plan as several projects were proposed by HBP, which might mean that the mining company will receive additional funds (Denková, 2018). Table 4-4 illustrates possible projects:

Table 4-4 Potential projects, beneficiaries and indicative budgets

Project name	Beneficiary	Indicative budget
Production of railway carriage chassis	HBP	€100mln
Automotive R&D centre	Brose	€125mln
ENO Novaky brownfield revitalization	Slovenske elektrarne	€100mln
Research centre for underground technologies	GA drilling and HBP	€2.5-32mln
Upper Nitra Education Centre	Trencin self-governing region	€8.2mln

Sources: (PMO, 2019; Seban, 2019)

4.1.2.4 Limitations: Possible effects of international finance, co-benefits and double counting on results

As indicated above, the availability of international finance may have significant effects on the observed costs of phasing out coal. In the case of Slovakia, this amount has been estimated at up to $2,500mln. Some of this funding may be made available through the EU. In the past, the Upper Nitra region has already benefitted from the ESIF: In the budgeting period 2014-2020, it had received €33.9mln by July 2018 (Filcak et al., 2018). An initial proposal estimates that out of the €7.5bln EU Just Transition Fund, €162mln might be allocated to Slovakia (European Commission, 2020). Even though the availability and effect of international finance is difficult to quantify and not possible within the scope of this thesis, it is likely to affect the observed costs of phasing out coal.

Similarly, it is beyond the scope of this thesis to quantify potential co-benefits of phasing out coal and supporting regional economic development through infrastructure investments or the support of local businesses. Another co-benefit of phasing out coal are saved expenses due to ending state subsidies for coal production. In the Slovak case, the termination of subsidies is estimated to save €100mln annually, and achieve annual health benefits of €500mln (IEA, 2018b). Another estimate suggests that closing the Novaky plant by 2023 compared to operating until 2030 results in decreased energy system costs of €388mln and in additional positive "social welfare consequences" of €160-170mln in the year following the phase-out (Donnari et al., 2018).

There are no studies on the potential of double counting in the case of the Slovak coal phase-out. However, this is estimated as relatively low as payments are either directed at HBP and would have not been made without the coal phase-out or have been recently earmarked. Additionally, envisioned sources for funding suggest that a majority is envisioned to be paid through international rather than national finance (Seban, 2019).

4.2 Greece

4.2.1 Background information

Table 4-5 Background information Greece

Capacity-related indicators		Cost-related indicators	
Functioning of government	9/12	Share of coal in electricity supply	34%
GDP/capita (USD)	20,300	Installed MW coal capacity	3,800
GDP (total) (USD bln)	220	Domestic coal production (ktoe)	4400
		Coal dependence	5%
		Nr of workers in coal sector	6500

Sources: (FreedomHouse, 2020; Global Energy Monitor, 2020; IEA, 2020e; Jewell et al., 2019; Vazquez-Hernandez et al., 2018; World Bank, 2020j, 2020d), coal capacity from Jan 2020, FoG from 2019, all other data from 2018. Data at 10% accuracy. For precise values see Appendix 1.2

4.2.1.1 Greek energy system and coal sector

In the past, coal was the largest domestic energy source in Greece and significantly supported the electrification of the country (Kordas, 2006). Currently, coal accounts for more than one third of Greece's electricity generation (see table 4-5). This has declined from a 69.8% share of electricity supply in 2002 (IEA, 2020e; Wehnert et al., 2017). Even though the use of coal has declined over time, it is still Greece's largest electricity source (IEA, 2020e). The low diversification of the Greek energy mix makes it one of the most coal-reliant EU countries (Mills, 2015; Popp, 2019). Even though most electricity is currently produced by fossil fuels, Greece is beginning to tap into its abundant renewables potential as wind, solar and hydro are increasingly deployed to produce electricity (IEA, 2020e; Mills, 2015; Wehnert et al., 2017). However, the share of natural gas in electricity production has also increased (IEA, 2020e; Wehnert et al., 2017). Greece also imports a relatively high share of its electricity (Mills, 2015).

Coal infrastructure in Greece is ageing: the average age of coal plants in Western Macedonia is 31 years (Buzatu, 2019; Popp, 2019). The mainland fleet consists of 14 coal power plants that together amount to about 4GW installed capacity (cp Table 4-5) (Tsagas, 2019). All coal plants belong to the Public Power Corporation (PPC), which has the exclusive right to produce electricity from lignite and also mines all lignite in Greece (Popp, 2019; Tsagas, 2019). Its majority shareholder at 51% is the Greek government (Popp, 2019; Tsagas, 2019). Over the last three years, PPC incurred net losses from operating its coal plants (Koutantou & Fenton, 2019; Koutantou & Harvey, 2019; Tsagas, 2019). These losses arose due to rising carbon emission costs, lower costs of alternative electricity sources and opening of the electricity sector to competition, which official lenders had asked from the Greek government (Koutantou & Fenton, 2019; Koutantou & Harvey, 2019; Popp, 2019) in the context of the Economic Adjustment Programmes (EAP) that the Greek government agreed with the EU, IMF and European Central Bank (ECB) after the financial crisis of 2008 (Popp, 2019). PPC agreed to sell up to 40% of its lignite capacity to break up its current monopoly, but has not been implemented this to date (Ganbold & Megaritis, 2019; Popp, 2019).

In comparison to other European countries, lignite-fired power generation in Greece is among the most expensive because domestic lignite is of comparatively low quality (Popp, 2019). The government long supported the production and use of domestic coal through subsidies such as capacity mechanisms and lobbied for free emission allowances for the coal sector under the EU ETS (Popp, 2019). However, the EU recently adopted regulations that power plants emitting over 550 grams CO_2 per kWh produced cannot be supported through capacity mechanisms (Ganbold & Megaritis, 2019). This affects both currently operating and planned coal plants: Ptolemaida V and Meliti II, envisioned to operate until 2050 (Ganbold & Megaritis, 2019; McNevin, 2019; Popp, 2019; Rovolis & Kalimeris, 2019; Tsagas, 2015). Additionally, the government planned investments to extend the operation of the Myntaio Thermal Power Station (TPS) beyond 2023 (Rovolis & Kalimeris, 2019). These plans had been made by a former government in place until 2015 which strongly supported the use of domestic lignite (Mills, 2015; Popp, 2019; Tsagas, 2019).

Most of these plans were however prohibited by Greece's Supreme Administrative Court after ClientEarth, WWF Greece and Greenpeace Greece had filed a legal challenge in 2017 (Arbinolo, 2019; Burton, 2019; ClientEarth, 2020). The only coal unit remaining under construction is Ptolemaida V (Europe Beyond Coal, 2020b). The ruling also revoked environmental permits of Megalopoli A & B units which emit sulphur dioxide and nitrogen oxides above EU standard, as their permits had been renewed without assessing environmental and health impacts of the plants' operations (Arbinolo, 2019; Burton, 2019; ClientEarth, 2020). A reduction of subsidies between 2013 and 2014 due to the austerity mechanism, a lignite fee and a local community tax for coal-fired power stations to support mining communities in preparations to phase out coal provided additional drivers of the coal decline (OECD, 2019; Worrall & Runkel, 2017).

The current conservative government, which was elected in July 2019, is keen to reform PPC and move away from the extensive use of coal for electricity generation (Koutantou & Harvey, 2019). Analysts assume that the main reason for this is the increasing inefficiency and costliness of domestic coal compared to other electricity sources, and additional pressure from the EU to phase out coal (Walker, 2019). Labour unions however resist the coal decline. PPC's largest labour union, GENOP/DEH, represents 18,000 workers and has successfully protested laws revoking workers' benefits in the past (Koutantou & Harvey, 2019; Popp, 2019). However, they have shown support for phasing out coal combined with a just transition strategy (Popp, 2019).

4.2.1.2 Greece's coal region: Western Macedonia

Western Macedonia is Greece's main coal region and produced about 80% of the domestic lignite in 2017 (Wehnert et al., 2017), providing about 50% of the country's electricity (Buzatu, 2019). Coal has been mined on an industrial scale since 1939 in Western Macedonia, driving the economic growth of the region (Buzatu, 2019). This influenced the coal-oriented mentality of locals (Buzatu, 2019; Wehnert et al., 2017) and inspired the positive perception of coal as ushering a "spirit of innovation" (Ministry of Environment and Energy, 2019b).

Currently, regional GDP in Western Macedonia is 25% lower than the national average in Greece (Popp, 2019). The region also has the 9th highest unemployment rate among all European regions at 27.6% (Rovolis & Kalimeris, 2019). In addition to the effect of the financial crisis, the decline of coal production has led to rising unemployment and a declining regional GDP especially since 2009 (Cami, 2018; Rovolis & Kalimeris, 2019; Wehnert et al., 2017). The diversification of the regional economy in Western Macedonia is comparatively low with energy production through lignite and hydro constituting its main economic activity (Popp, 2019; Rovolis & Kalimeris, 2019). Studies estimate that, considering direct employment, PPC provides 6.3% of all jobs in Western Macedonia (Popp, 2019) and 45.9% of jobs in the secondary sector (Wehnert et al., 2017). Additionally, Kordas (2006) estimates that one job in the lignite industry leads to eight working places in subsidiary sectors in the same region. Western Macedonia, which is a traditionally less densely populated region, also faces an additional population decline which started in the 1960s due to its demographic structure: the largest age group among the regional population is 65 years and older (Popp, 2019; Rovolis & Kalimeris, 2019; Wehnert et al., 2017).

Despite the high reliance on the electricity and coal sectors, local stakeholders seem to have discussed phasing out coal before commitments were made on national level, with local mayors expressing their support for a coal phase-out in combination with a just transition strategy as early as 2015 (Popp, 2019). Additionally, Western Macedonia is one of the pilot regions of the EU's Coal Regions in Transition Platform and receives technical assistance to phase out coal, since before the national phase-out commitment (Flisowska & Moore, 2019).

4.2.1.3 Coal phase-out policy

At the UN Climate Summit in 2019, the Greek prime minister at the time, Kyriakos Mitsokakis, announced 2028 as the end-date for the use of coal for electricity generation in Greece (Buzatu, 2019; McNevin, 2019; PPCA, 2019c), despite previous political support for coal (Tsagas, 2019). This commitment has been reiterated in the most recent NECP, which also includes a timeframe outlining the dates for individual coal power plants to be shut down (see Table 4-6). This table does not include the new unit Ptolemaida V, a 660 MW unit which is currently under construction and planned to be retired in 2028 (Europe Beyond Coal, 2020a, 2020b). The NECP seems to foresee the substitution of coal-fired power generation mainly through wind, solar PV and natural gas (Ministry of Environment and Energy, 2019b).

Table 4-6 Timeframe for shutting down lignite-fired plants

Lignite-fired plant	Rated capacity	Year of shutdown
Kardia 1	275	2019
Kardia 2	275	2019
Kardia 3	280	2021
Kardia 4	280	2021
Agios Dimitros 1	274	2022
Agios Dimitros 2	274	2022
Agios Dimitros 3	283	2022
Agios Dimitros 4	283	2022
Agios Dimitros 5	342	2023
Amyntaio 1	273	2020
Amyntaio 2	273	2020
Florina/Meliti	289	2023
Megalopolis 3	255	2022
Megalopolis 4	256	2023

Source: (Ministry of Environment and Energy, 2019b, p. 96)

Phasing out coal means laying off coal workers, primarily in coal-dependent Western Macedonia, which workers unions have protested (Koutantou & Fenton, 2019). To offset potentially negative effects of a coal phase-out, municipalities in Western Macedonia had previously requested the establishment of a "just transition fund" which was rejected at first (Rovolis & Kalimeris, 2019). However, as the coal phase-out became a reality, the government agreed to support the Florina and Kozani regions between 2018 and 2020 (Ministry of Environment and Energy, 2019a) and established a "just transition fund" in January 2019 (Popp, 2019). It is financed from 6% of annual revenues from auctioning emission allowances (Ministry of Environment and Energy, 2019a; Popp, 2019). A Just Development Transition Master Plan with concrete projects is currently prepared by an inter-ministerial committee, set up in December 2019, and planned to be presented in mid-2020 (Ministry of Environment and Energy, 2019b). Consultations with local stakeholders are planned as part of the preparation process (Ministry of Environment and Energy, 2019b). Support for coal regions will also include the pay-out of a tax charged to PPC at 0.5% of its annual turnover, payable to local communities where mining activities take place, which is owed to these communities since 2014 and amounts to approximately €130mln (Ministry of Environment and Energy, 2019b; Organisation for Economic Co-operation and Development (OECD), 2019).

4.2.2 Compensation cost of Greek coal phase-out

4.2.2.1 RQ1: What are the avoided emissions of the coal phase-out?

The avoided emissions due to the Greek coal phase-out are 128.2MtCO_2 from 2019 to 2028. This means that on average, per year, 12.8 MtCO_2 are avoided, 20.6% of total CO_2 emissions in 2018. Total CO_2 emissions in Greece in 2018 amounted to 62 Mt (IEA, 2020e).

4.2.2.2 RQ2: How high are the compensation costs of the coal phase-out?

The estimated lower boundary amounts to $50.5mln, pledged to be payed to mining communities in the Florina and Kozani regions and the Municipality of Megalopolis between 2018 and 2020 (Ministry of Environment and Energy, 2019a). The estimated upper boundary, amounting to $219.9mln, additionally includes an estimated $169.4mln. This is derived from the statement that regional support is planned to continue until 2030 (Ministry of Environment and Energy, 2019a). This might change however, as the support is proportionally derived from emission auctioning revenues which might change in the future (Ministry of Environment and Energy, 2019a). Neither calculation includes the amount of €130mln mentioned in the final NECP, as this is assumed to be payed from PPC's revenues (Ministry of Environment and Energy, 2019a; OECD), 2019).

Table 4-7 Total and relative costs, upper and lower boundaries, in USD2018mln

Type of cost	Lower boundary	Upper boundary
Total	$51mln	$220mln
Total/avoided MtCO₂	$0.4mln	$2mln
Total/worker	$0.008mln	$0.03mln
Total/year	$5mln	$22mln

Sources: Cost/worker includes directly employed workers in both coal mines (4900) and power plants (1600) (Vazquez-Hernandez et al., 2018). Cost/year is calculated over 10 years, as the phase-out was announced in 2019 and is to be completed until 2028 (Ministry of Environment and Energy, 2019b; PPCA, 2019c). Data at 10% accuracy.

An alternative estimate of the cost of a "just transition" strategy to alleviate negative effects of phasing out coal in Western Macedonia has been estimated at €2.3 bln (Cami, 2018; Rovolis & Kalimeris, 2019), a magnitude higher than my upper boundary estimate.

4.2.2.3 RQ3: How are the compensation costs allocated among actors and purposes?

The support will be allocated among many different purposes, including investment and tax incentives supporting economic diversification, support for the improvement of infrastructures, local agriculture and tourism sectors, retraining workers and more (Ministry of Environment and Energy, 2019b). However, who exactly the beneficiaries are and how much money will be allocated to which purpose is to be specified in the upcoming Just Development Transition Master Plan which is to be finished by mid-2020 and can thus not be included in this analysis.

4.2.2.4 Limitations: Possible effects of international finance, co-benefits, double counting on results

A potential reason for the difference between the alternative estimate (Cami, 2018; Rovolis & Calimeris, 2019) and the estimate in this study is that the effect of international finance could not be quantified here. It is possible that international finance has a significant effect on the costs of phasing out coal in Greece. The final NECP states that "The Greek government have the political will and the required know-how to […] claim increased funds from EU financing funds, from the Just Transition Fund in particular" (Ministry of Environment and Energy, 2019b, p. 6). According to the most recent estimate, Greece is eligible to receive €66mln from this specific fund (European Commission, 2020). However, other EU structural investment funds also address decarbonization measures. Quantifying the amount of international finance used for phasing out coal in the Greek context, though beyond the scope of this thesis, is likely to significantly increase the total amount of financial compensation received by affected actors.

Co-benefits additionally may affect the costs of phasing out coal. In addition to decreased health and environmental costs that occur in all countries, in the Greek context, phasing out coal arguably has large effects on the Greek electricity price, making it much lower than it would otherwise be (Ganbold & Megaritis, 2019) which may support energy-intensive industries that are a main electricity consumer in Greece (IEA, 2020e). Additionally, supporting regional development may lead to a higher regional GDP and increase government tax revenue.

4.3 Finland

4.3.1 Background information

Table 4-8 Background information Finland

Capacity-related indicators		Cost-related indicators	
Functioning of government	12/12	Share of coal in electricity supply	9%
GDP/capita (USD)	50,200	Installed MW coal capacity	1,900
GDP (total) (USD bln)	280	Domestic coal production (ktoe)	0
		Coal dependence	79%
		Nr of workers in coal sector	1100

Sources: (FreedomHouse, 2020; Global Energy Monitor, 2020; IEA, 2020c; Jewell et al., 2019; OSF, 2019a; Vazquez-Hernandez et al., 2018; World Bank, 2020b, 2020b), coal capacity from Jan 2020, FoG from 2016, all other data from 2018. Data at 10% accuracy. For precise values see Appendix 1.3.

4.3.1.1 Finnish energy system and coal sector

In contrast to the other countries, there is no domestic coal mining of either lignite or hard coal: Finland imports most of its coal from Russia (IEA, 2018a). Finland domestically produces peat, which is sometimes categorized as a type of coal, for instance by the IEA. Finnish national statistics, however, differentiate between peat and coal, and peat is excluded from the current coal phase-out – instead, the latest NECP includes the aim of "halving the use of peat in energy production by 2030" (Ministry of Economic Affairs and Employment, 2019a, p. 19). Reportedly, a complete ban of the use of peat in power production is debated, a Just Transition commission for phasing out peat has been formed and the use of EU funds to support peat regions is envisioned (Harkki, 2019; Mäkitalo, 2019; Yle Uutiset, 2020).

Not including peat, coal provided 9% of Finnish electricity (see Table 4-8) and 20% of its district heat in 2018 (Kauranen & Karagiannopoulos, 2019; OSF, 2019b, 2019a, 2019c). TPES is dominated by domestically produced biomass and nuclear energy as well as oil which is mainly imported from Russia (IEA, 2018a). Even though coal does not provide a large share of electricity, it provides one fifth of district heating (IEA, 2018a). While northern regions primarily rely on peat and biomass for district heating, cities along the coast such as Helsinki or Vaasa with access to ports still mainly rely on coal (Heiskanen et al., 2019; IEA, 2018a; Lund, 2017; Teivainen, 2018). In 2017, coal for instance supplied 60% of district heat and 30% of electricity in Helsinki (Teivainen, 2018). Phasing out coal thus has major consequences for the district heating systems of these cities (Heiskanen et al., 2019; Lund, 2017; Teivainen, 2018).

Since 2007, the supply of fossil fuels including oil, coal, natural gas and peat declined by almost 50%, whereas the supply of biomass and waste increased by 30% (IEA, 2018a; Pilpola & Lund, 2018). Even though energy generated from biomass is politically considered as carbon neutral, environmental advocates criticize an increased supply of biomass (Bixel & Jones, 2019; J. Hill, 2019; Lund, 2017), while others question the feasibility of substituting coal through biomass Heiskanen et al., 2019) as the supply of domestic biomass may not be able to replace all coal capacity (Teivainen, 2018).

Finnish politics has recently increased efforts to mitigate climate change and reduce the share of fossil fuels (IEA, 2018a; Lund, 2017). The government set ambitious climate and emission targets, envisioning increasing energy efficiency and fuel switching to renewables and nuclear (IEA, 2018a). Nuclear plays an important role as energy demand is expected to rise, creating the need for additional capacity (Morgan, 2018a). Two reactors are under construction and expected to begin operating before 2025: Olkiluto runs several years behind the originally envisioned start date and is currently expected to be dispatched in 2020, whereas Hanhkivi is expected to start operating in 2024 (Argus Media, 2018; IEA, 2018a; Lund, 2017; Pilpola & Lund, 2018). Public opinion is in favour of nuclear energy, which may be one reason why potential for renewables such as wind has not yet been extensively exploited (Lund, 2017).

4.3.1.2 Coal phase-out policy

The commitment to phase out coal by 2030 was already mentioned in Finland's National Energy and Climate Strategy 2016 (Kauranen & Karagiannopoulos, 2019; Lund, 2017). This commitment is reiterated in the final NECP (Ministry of Economic Affairs and Employment, 2019a) and the government programme (Government of Finland, 2019). In 2017, Finland was among the first countries to join the PPCA (Kauranen & Karagiannopoulos, 2019; Lund, 2017). In April 2019, the law on the ban of coal as an electricity source by May 2029 came into force (Ministry of Economic Affairs and Employment, 2019b). This ban does not allow coal-fired power plants with CCS technologies (Dockrill, 2016). After the phase-out date, coal may only be used in case of a national emergency (Kauranen & Karagiannopoulos, 2019). While some support this policy as a "clear-cut plan without loopholes", others criticize it as unambitious due to the low amount and the age of installed coal capacity (Bixel & Jones, 2019).

Reportedly, the energy minister was in favour of phasing out coal by 2025 (Morgan, 2018a). The relatively long transition period until 2030 is to ensure the "reconciliation of different kinds of public and private interests" (Ministry of Economic Affairs and Employment, 2019b). This may be in response to resistance against the coal phase-out which was mainly expressed by Finnish coal utilities when it was first announced in 2016, who criticized it as an expensive but ineffective measure (Morgan, 2018a; Teivainen, 2016). Responding to calls for compensation (Teivainen 2016), the Finnish prime minister's office stated that the government is not liable to compensate utilities (Prime Minister's Office, 2018).

Even though coal is arguably not the most politically contentious sector to phase out in Finland compared to peat and biomass (Burtsov, 2019), the Finnish coal phase-out plan includes financial compensation for affected CHP plants that agree to accelerate the coal phase-out to 2025.

4.3.2 Compensation cost of Finnish coal phase-out

4.3.2.1 RQ1: What are the avoided emissions of the coal phase-out?

The estimated avoided emissions due to the Finnish coal phase-out policy are 23.3 MtCO_2. This may overestimate avoided emissions as the applied methodology does not allow for a fractional retirement year. Instead of May 2029, the end of 2028 was used as the closest possible approximation. Assuming the phase-out by 2028, emissions are avoided over 13 years, as the phase out was first announced in 2016. On average, the coal phase-out thus avoids 1.8 MtCO_2 per year, 4.1% of total CO_2 emissions in 2018. In 2018, total CO_2 emissions in Finland amounted to 44Mt (IEA, 2020c).

4.3.2.2 RQ2: How high are the compensation costs of the coal phase-out?

There is only one pledged amount of financial compensation: $76.2mln. The money is reallocated by lowering the required annual production level proposed for a tendering scheme mainly supporting wind power generation from 2 TWh to 1.4 TWh (Borenius, 2018; Ministry of Economic Affairs and Employment, 2018).

Table 4-9 Total and relative costs, upper and lower boundaries, in USD2018mln

Type of cost	Lower boundary	Upper boundary
Total	$76mln	$76mln
Total/avoided $MtCO_2$	$3.3mln	$3.3mln
Total/worker	$0.07mln	$0.07mln
Total/year	$5.4mln	$5.9mln

Sources: Cost/worker includes direct employees of coal plants (1100) (Vazquez-Hernandez et al., 2018). Cost/year has two values: The lower boundary is calculated over 13 years as the phase-out pledge was made in 2016 (Dockrill, 2016). The upper boundary is calculated over 11 years as the phase-out law came into force in 2019 (Ministry of Economic Affairs and Employment, 2019b). Data at 10% accuracy.

4.3.2.3 RQ3: How are the compensation costs allocated among actors and purposes?

Only district heating companies which agree to accelerate phasing out coal by 2025 are eligible for compensation (Ministry of Economic Affairs and Employment, 2019a). Half of the money is earmarked to support the use of biomass as a substitute for coal in CPH plants (Borenius, 2018; Europe Beyond Coal, 2020a; Galgóczi, 2019; Ministry of Economic Affairs and Employment, 2018). The other half will be used for new solutions other than gas or biomass, mainly non-combustion technologies such as heat pumps or heat storage (Borenius, 2018; Europe Beyond Coal, 2020a; Galgóczi, 2019; IEA, 2018a).

4.3.2.4 Limitations: Possible effects of international finance, co-benefits, double counting on results

Effects of international finance on the cost of phasing out coal in Finland are likely to be very low, as the total amount of pledged compensation and the origin of this money is known. This also solves the issue of double counting: in the Finnish case, the compensation is clearly an opportunity cost that leads to money being spent on phasing out coal rather than accelerating the deployment of renewables. Even though the just transition fund estimates to pay €165mln to Finnish regions (European Commission, 2020), it is much more likely that this will be used to support the transition away from peat.

It is likely that the Finnish coal phase-out will lead to co-benefits such as decreased health and environmental costs and possibly decreased fuel costs in the long run, if more heat pumps are used to generate heat. It is however likely that the costs of district heating will rise in the most affected cities, Vaasa, Helsinki and Turku (Borenius, 2018).

4.4 Spain

4.4.1 Background information

Table 4-10 Background information Spain

Capacity-related indicators		Cost-related indicators	
Functioning of government	11/12	Share of coal in electricity supply	14%
GDP/capita (USD)	30,400	Installed MW coal capacity	9,900
GDP (total) (USD bln)	1,400	Domestic coal production (ktoe)	780
		Coal dependence	91%
		Nr of workers in coal sector	6700

Sources: (FreedomHouse, 2020; Global Energy Monitor, 2020; IEA, 2020g; Jewell et al., 2019; Vazquez-Hernandez et al., 2018; World Bank, 2020l, 2020f), coal capacity from Jan 2020, all other data from 2018. Data at 10% accuracy, for precise values see Appendix 1.4.

4.4.1.1 Spanish energy system and coal sector

The Spanish coal sector includes domestic hard coal and lignite mining and electricity generation from coal. About 85% of domestically produced coal is used for electricity generation and the rest for steel production (Del Río, 2017). This section first discusses the coal mining sector and then the power sector.

Domestic coal production in Spain was supported through government subsidies as early as in the 1980s (Greenpeace, 2016). However, in 1986, Spain joined the EU, which pushed for liberalization of the electricity market and decreasing coal subsidies (Bridle et al., 2017; Greenpeace, 2016; Rentier et al., 2019). The introduction of competitiveness in the electricity sector in 1997 also limited opportunities for direct government interventions and led to the expansion of renewable energy (Rentier et al., 2019). The Spanish government however continued to support the coal industry as it declined, with continuous compensation schemes from 1998 to 2018. The typically included obligations and compensation for thermal plants to buy more expensive domestic coal instead of imported coal, compensation for laid-off workers such as early retirement schemes and training opportunities, improvement of local infrastructure and support for alternative businesses in the affected coal regions (Del Río, 2017; Greenpeace, 2016). These support schemes were conditional to the gradual reduction of the amount of coal produced and consumed for electricity production (Del Río, 2017). This decline was driven by several technoeconomic factors: Prices of international coal decreased since 2011, which led to an increased use of imported instead of domestic coal (Del Río, 2017; Proctor, 2018; Rentier et al., 2019). Additionally, domestic is of lower quality than imported coal (Krämer, 2017; Wehnert et al., 2017), mainly imported from Russia and Colombia (Patuleia & Littlecott, 2019). Production of all types of coal steeply decreased since 1990, and lignite mining ended in 2008 (Del Río, 2017; IEA, 2020g). Most recently, EU regulations prohibiting subsidies for uncompetitive coal mines led to closing all remaining hard coal mines (Patuleia & Littlecott, 2019).

In 2010, the EU finalized legislation that required member states to stop financial support for coal mines unless this aid was coupled with a planned closure of the mines (Rentier et al., 2019). This decision led to social unrest in Spain, where the two largest coal mining companies faced financial difficulties to the extent that they stopped paying workers, leading to the "Black March" in 2012 when coal miners walked into Madrid to protest the EU decision (Krämer, 2017; Rentier et al., 2019). The Spanish government thus requested a permission to extend state aid for coal mining, which was granted by the EU until 2018 (Krämer, 2017; Missé, 2010) under the condition to elaborate a closure plan for all mines and thus effectively end domestic coal production (Krämer, 2017; Rentier et al., 2019). Scholars have identified several factors influencing continued government support for coal subsidies in Spain: energy security concerns due to the intermittency of renewables and the strong constituency of affected actors including workers' unions, municipal and regional governments and industry associations that lobbied for continued support of coal production (Del Río, 2017). This is exemplified by the observation that mining workers' unions constitute a significant part of the voters of the Spanish Socialist Workers' Party (PSOE) (Bridle et al., 2017).

This constellation of powerful and influential actors pushed for continuing and relatively generous compensation schemes, including the Just Transition Agreement concluded between the Spanish national government and the mining unions in 2018 (Bridle et al., 2017; Ministerio para la transición ecológica, 2019a; Rentier et al., 2019). Spanish compensation schemes have been criticized as not always being successful, for instance as newly opened companies closed after subsidies ended, and relatively generous early retirement schemes may have disincentivized workers to seek new employment (Bridle et al., 2017). Overall, phase-out compensation in the past has arguably focused on subsidizing affected actors such as utilities and laid off workers than effectively create new job opportunities (Rentier et al., 2019).

Even though coal mining stopped in the beginning of 2019 (Planelles, 2020; Worrall & van den Burg, 2017), the government expected plants running on imported coal to provide electricity at least until 2030 (Planelles, 2019). Electricity is currently generated in 14 coal-fired power plants (Europe Beyond Coal, 2020b), contributing 14% of electricity generation in 2018 (see Table 4-10). The share of coal in electricity production significantly decreased between 1990 and 2010, when natural gas and wind power were increasingly deployed (IEA 2020g, Rentier et al., 2019). However, coal power in absolute terms did not decrease as strongly (Del Río, 2017; IEA, 2020g; Rentier et al., 2019). Between 2010 and 2015, the share of coal increased somewhat as a result of direct government intervention ensuring a preferential merit order and compensation payments for thermal plants using more expensive domestic coal (Del Río, 2017; IEA, 2020g; Rentier et al., 2019) among other drivers such as decreasing trust in nuclear after the Fukushima accident, high gas prices and, in 2015, low electricity generation from hydro and wind due to weather conditions (Del Río, 2017).

Notwithstanding this temporary increase, increased electricity production through renewables, seasonally low gas prices, the abolishment of a tax on gas-fired electricity generation and lower wholesale electricity prices led to an unprecedented low use of coal in summer 2019 (Baratti, 2019; Bronte, 2019; Champion & Vickers, 2019; Planelles, 2019, 2020; (Patuleia & Littlecott, 2019; Rathi & Hodges, 2020), even despite low hydroelectricity production (Patuleia & Littlecott, 2019; Planelles, 2019). Additionally, EU policies such as carbon pricing under the EU ETS and emissions standards became more stringent (Binnie, 2018; Flisowska & Moore, 2019; Patuleia & Littlecot, 2019; Del Río, 2017). The declining use of coal in 2019 was mostly replaced by gas (Argus Media, 2019b; Bronte, 2019), supplied by infrastructure that had been underused for years and was operating at "historic highs" during 2019 (Planelles, 2019). The limited use of existing energy infrastructure was caused by large overcapacities of Spain's electricity system (Europe Beyond Coal, 2020a), which is arguably the "most oversupplied electricity market in Europe" (Rathi & Hodges, 2020). Overcapacity was caused by an unforeseen surge of investment in renewable energy, increased instalment of combined cycle gas turbines (CCGT) and lower than expected electricity demand (Del Río, 2017).

The technoeconomic drivers presented above led coal utilities to operate at economic losses (Carbon Tracker Initiative, 2019), indicating a sooner phase-out of coal-generated electricity than expected by the government (Planelles, 2019). Spain's largest utility, Iberdrola, announced coal retirements as early as 2017, which was opposed by the government at the time (Champion & Vickers, 2019; Robert, 2017). Endesa and the former Spanish government pushed for extending the life of three coal plants as recently as 2018, but Spain's Comisión Nacional de Mercados y la Competencia (CNMC) (eng: National Commission of Markets and Competition) prohibited this due to the existing overcapacity. More recently, Endesa announced the phase-out of some of these same coal plants (Patuleia & Littlecott, 2019; Proctor, 2018; Wynn et al., 2018) and Iberdrola has become a PPCA member (Champion & Vickers, 2019). In line with utilities' retirement plans, 83% of existing coal capacity in Spain is likely to retire in 2020 (Patuleia & Littlecott, 2019). Both companies seem to invest in expanding renewables such as solar and wind for electricity generation, which could limit the further increase of the importance of gas (Argus Media, 2019b; J. S. Hill, 2019; Patel, 2020; Rathi & Hodges, 2020).

Political support for coal decreased with the socialist government coming to power in 2018. It communicated ambitions to unlock investment in accelerating a low-carbon energy transition and created the Ministry for Ecological Transition which subsumes responsibility for two policy areas: energy and climate change (Binnie, 2018; Champion & Vickers, 2019). The ministry established a strategic framework to decarbonize the Spanish economy, including a draft Climate Change and Energy Transition law, the NECP 2021-2030 and an accompanying Just Transition and Energy Poverty Strategy (Ribera, 2020). Resistance of affected workers may oppose these transitions through well-organized workers' unions: The Comisiones Obreras (CCOO) was founded after a strike at a mine in 1957, and the Union General de Trabaradores (UGT) was established by Pablo Iglesias who was also involved in founding the political party PSOE (Bridle et al., 2017) (see also section 2.3.2.1). Recent protests include the Marcha Negra (Black or Dirty Marches) in the 1990s and in 2012, protesting decreasing subsidies and subsequent job losses (Industriall, 2018; Keeley, 2020).

4.4.1.2 Spanish coal regions: Asturias, Castilla y Léon and Teruel

Coal mining in Spain began in the 16th century (Keeley, 2020) and played an important role in the energy history of Spain as the first domestic energy source (Rentier et al., 2019). Coal mining is mainly concentrated in the South of Asturias, the north of the León province and in the province Teruel in the region Aragon (Del Río, 2017) (see also Figure 4-2).

León and Asturias are economically dependent on coal mining: in Asturias, for instance, the mining industry contributed 1% of the regional GDP in 2011 (Del Río, 2017; Greenpeace, 2016). The decline of the coal industry has caused a substantial increase in the regional unemployment rate since 1990 (Del Río, 2017). In the province Teruel, employment is highly concentrated in the declining mining sector. Especially young people thus leave the region, leading to a substantial decrease in population in the last 30 years (Neslen, 2018; Wehnert et al., 2017). In addition to economic effects of phasing out coal, the identity and societal structures in coal mining regions are strongly connected to the sector (Keeley, 2020; Neslen, 2018). In the past, these factors led to strong localized resistance against coal closures and decreasing subsidies (Baratti, 2019; Keeley, 2020).

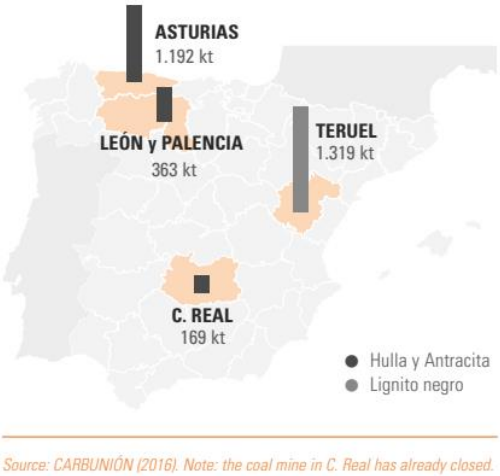


Figure 4-2 National coal production in 2014, Spain

Source: (Del Rio, 2017, p. 7)

4.4.1.3 Coal phase-out policy

Spain differs from the other countries as there is no law or policy that mandates a coal phase-out since the government assumes that coal-fired electricity generation will be phased out latest by 2030 due to the techno-economic and political drivers described in section 4.4.2.1 (Flisowska

& Moore, 2019; Morgan, 2018b; Patuleia & Littlecott, 2019). The final NECP submitted to the EU in January 2020 estimates 0 GW installed coal capacity by 2030 (Ministerio para la transición ecológica, 2020, p. 47). Observers estimate that coal might be phased out between 2025 and 2027 (Baratti, 2019; Bronte, 2019; Champion & Vickers, 2019; Europe Beyond Coal, 2020a; Patuleia & Littlecott, 2019; Rathi & Hodges, 2020).

Coal mining in Spain ended in 2019 as subsidies became prohibited by EU regulations. This was accompanied by an agreement between the Socialist government and the mining unions CCOO, UGT and Union Sindical Obrera (USO), agreeing to a just transition programme (Europe Beyond Coal, 2020a; Industriall, 2018; Patuleia & Littlecott, 2019; Ribera, 2020).

4.4.2 Compensation cost of the Spanish coal phase-out

4.4.2.1 RQ1: What are the avoided emissions of the coal phase-out?

If current assumptions are correct and coal in Spain is phased out latest by 2030, avoided emissions are estimated at 38.1MtCO_2. Assuming the start of the politically driven phase-out in 2019, as this was when government statements indicated a phase-out in 2030, emissions are avoided over 12 years. This means that on average, 3.2MtCO_2 emissions are avoided annually, 1.3% of total CO_2 emissions in 2018 which amounted to 245 MtCO_2 (IEA, 2020g).

4.4.2.2 RQ2: How high are the compensation costs of the coal phase-out?

Costs of the Spanish coal phase-out are estimated between $431.8mln and $1896.8mln. The lower boundary includes compensation pledged according to the agreement between workers' unions and the Spanish government in 2018. Even though the original agreement encompassed about €250mln compensation for coal miners (Neslen, 2018), the legislation implementing the agreement only included $84.1mln (€100mln) (Ministerio para la transición ecológica, 2018). The Just Transition Strategy, which was finalized in 2019, includes support for coal mining regions of $109.8mln, to be payed between 2019 and 2023 and $129.8mln for investments in renewable energy (Ministerio para la transición ecológica, 2019a).

It also earmarks up to €100mln for future transition agreements with affected actors in any of the regions (Ministerio para la transición ecológica, 2019a). As this money has not been allocated to specific projects and has not been fixed in a law at the time of writing, it only counts towards the upper boundary. It is part of a total of $504.6mln (€600mln) according to Teresa Ribera, the responsible minister, announcing that the government aims to use this money for future just transition agreements (Ministerio para la transición ecológica, 2019b). Talks with the region of Aragón for relief of coal mining communities in Teruel out of this budget have reportedly begun (Ministerio para la transición ecológica, 2019a).

The upper boundary also includes $960.3mln which is aid pledged in 2011 to be payed out until 2021 to 15 coal mining companies (State Aid SA.34332 (2012/NN), 2016). This amount may overestimate the complete amount of aid payed as the Spanish authorities were to deduct the increase in the value of land from rehabilitation and renaturation activities from the amount of aid (State Aid SA.34332 (2012/NN), 2016).

Table 4-11 Total and relative costs, upper and lower boundaries, in USD2018mln

Type of cost	Lower boundary	Upper boundary
Total	$430mln	$1900mln
Total/avoided MtCO_2	$11mln	$50mln
Total/worker	$0.06mln	$0.3mln
Total/year	$36mln	$160mln

Sources: Cost/worker includes employees of both coal mines (3400) and coal plants (3300) (Vazquez-Hernandez et al., 2018). Cost/year is calculated over 12 years, as the government estimate of coal capacity being phased out by 2030 was mentioned in the NECP (Ministerio para la transición ecológica, 2020), and the "just transition" began in 2019 (Ministerio para la transición ecológica, 2019a). Data at 10% accuracy.

4.4.2.3 RQ3: How are the compensation costs allocated among actors and purposes?

Table 4-12 Allocation of costs among actors and purposes

Agreement	Amount	Beneficiaries and purpose
Just transition agreement with miners, 2018	$84.1mln	Affected workers: early retirement schemes, creation of a job bourse to help workers access retraining schemes and find new jobs
Just transition strategy	$109.8mln	Support for affected mining regions (2019-2023)
	$129.8mln	Investment in renewables
Government announcement	$504.6mln	Future just transition agreements with regional affected actors
Money pledged for previous coal industry decline	$307.3mln	Compensation for production losses of companies
	$653mln	Exceptional costs of companies

Sources: (State Aid SA.34332 (2012/NN), 2016; Ministerio para la transición ecológica, 2018, 2019a, 2019b)

The distribution of the money pledged through the first Just Transition agreement is managed by the Instituto para la Reestructuración de la minería del Carbón y el Desarrollo alternative de las comarcas Mineras (Ministerio para la transición ecológica, 2018). About 600 workers in Asturias, Aragón and Castilla y Léon are expected to benefit from the scheme, with about 60% being eligible for early retirement (Neslen, 2018). Table 4-12 lists pledged compensation, beneficiaries and purposes. Exceptional production losses of companies include social welfare benefits, of which 595 workers are estimated to benefit, payments of pensions and allowances for laid-off workers, applicable to about 2950 workers, additional underground safety work resulting from closure of the coal production units, mining damages, costs related to the rehabilitation of the former mining sites and costs of surface recultivation (State Aid SA.34332 (2012/NN), 2016).

4.4.2.4 Limitations: Possible effects of international finance, co-benefits, double counting on results

The availability of international finance may affect the cost of phasing out coal in Spain, as mobilizing international finance to support the government in its coal phase-out has been called for (Piven, 2019). (Wehnert et al., 2017) analyze the potential role of EU structural funds in phasing out coal. They find that while actors in Aragon applied for funding for several projects connected with phasing out coal in the Programming Period 2014-2020, at the time of writing in 2017, none of the projects had been awarded funding. Analyzing the content of the projects that were submitted, they argue that even though EU structural funds may potentially support phasing out coal in the region, this potential had not been realized due to a lack of regional implementing capacities (Wehnert et al., 2017). The proposed EU Just Transition Fund may change this by allocating money to Spain: currently, the amount to which Spain is eligible is estimated at €307mln (European Commission, 2020).

The extent to which double counting may affect the cost of phasing out coal seems to be rather small, as much of the support is directed at compensating affected workers, which would not have been spent had there not been a coal phase-out. Regarding projects for regional development, such as infrastructure projects, this is difficult to estimate and would require an analysis of regional budget plans to assess whether similar projects were previously planned. Finally, compensation schemes and phasing out coal itself may have co-benefits such as reducing air pollution and thus reducing public health and environmental costs or supporting regional economic growth.

4.5 Canada

4.5.1 Background information

Table 4-13 Background information Canada

Capacity-related indicators		**Cost-related indicators**	
Functioning of government	12/12	Share of coal in electricity supply	8%
GDP/capita (USD)	46,200	Installed MW coal capacity	8,500
GDP (total) (USD bln)	1,700	Domestic coal production (ktoe)	27,700
		Coal dependence	0%
		Nr of workers in coal sector	3500

Sources: (FreedomHouse, 2020; Global Energy Monitor, 2020; IEA, 2020a, 2020a; Jewell et al., 2019; Task Force, 2019a; World Bank, 2020g, 2020a). coal capacity from Jan 2020, FoG from 2017, all other data from 2018. Data at 10% accuracy, for precise values see Appendix 1.5

4.5.1.1 Canadian energy system and coal sector

There is both coal mining and electricity generation from coal in Canada, operated by several companies, some combining both coal mining and electricity generation from coal (Government of Canada, 2020). Domestically mined coal is not only used for electricity generation but also for coking and steelmaking and large quantities are exported, as several regions have abundant and profitably mineable coal reserves (Government of Canada, 2020). In 2018, Canada was the world's fourth largest exporter of metallurgical coal (Government of Canada, 2020), and coal constituted 15% of the total goods exports of Canada (Morena et al., 2018). The volume of imported coal has however decreased over time (Government of Canada, 2020).

Even though the share of coal in electricity production on national level is 8% (see Table 4-13), this causes over 70% of electricity sector CO_2 emissions (Government of Canada, 2020; PPCA, 2020a). Oil and gas also provide a significant share of electricity production. Canada is also the biggest supporter (per GDP) of oil and gas production among the G7 countries (Geddes & Gencsü, 2019). This may be perceived as contrasting Canada's climate leadership, which is shown through Canada co-founding the PPCA, and its financial support for climate transition in developing countries in the Americas and the Caribbean (Government of Canada, 2019c). "An oil-dependent economy that positions itself politically as an international climate leader, Canada exemplifies many of the tensions of the clean energy transition" (Morena et al., 2018).

Coal consumption has significantly decreased since 1990 (IEA, 2020a; Szoller, 2019). Canada is among the six OECD countries with the highest reduction in coal use between 2012 and 2017 (Schindler, 2019). One reason for the decline of coal-fired power generation is for instance declining local energy demand and increasing economic competitiveness of alternative energy sources, accelerated by regulations on both federal and regional levels (Schindler, 2019): first federal GHG regulations introduced in 2012 supported the phase-out of older and inefficient coal plants by 2015 (Bennett, 2018; Holly, 2010). Despite this decline, there is ongoing financial support for coal on both national and regional level, such as R&D funding for CCS, mine development tax credits, regional government ownership of coal companies and tax exemptions for coal production (Geddes & Gencsü, 2019). Regional policies are significant as Canadian provinces have full authority over local electricity systems (Szoller, 2019).

Ontario already phased out coal-fired electricity in 2014, which, as some argue, has enabled the current national coal phase-out (European Commission, 2019): A strong coalition of actors raising awareness regarding air pollution and health issues due to coal-powered electricity generation garnered public support for phasing out coal (Harris et al., 2015; Rosenbloom, 2018). Public support for phasing out coal and economic drivers such as the increased economic competitiveness of natural gas and renewables compared to coal led to a consensus among all three major parties in Ontario to implement a coal phase-out (Harris et al., 2015; Robins & Rydge, 2019; Rosenbloom, 2018). In 2001, a Select Committee on Alternative Fuel Sources was elected comprising members of all political parties, which recommended phasing out coal by 2015 (Rosenbloom, 2018). Even though there was some opposition to the coal phase-out among large-scale industrial coal users, workers' unions and communities where coal plants were situated, this opposition was not strong enough to override the larger public concern regarding environmental and health effects of coal powered energy generation (Harris et al., 2015; Rosenbloom, 2018). Additionally, coal utilities were traditionally not politically powerful as they were largely owned by the Government of Ontario, which was able to absorb the techno-economic costs of decommissioning the plants (Harris et al., 2015; Robins & Rydge, 2019; Rosenbloom, 2018). There was also no domestic coal mining in the region, leading to relatively limited job losses and effects on local communities (Harris et al., 2015; Rosenbloom, 2018). Even though job losses were of concern to local stakeholders, they were reportedly able to be replaced to a large extent (Harris et al., 2015).

4.5.1.2 Canada's coal regions

Even though Ontario was able to implement its regional coal phase-out with little resistance, other regions may face higher barriers of phasing out coal as the regional importance of coal production and consumption differ among regions (see table 4-14). Regions in cursive are those that are recognized as significantly negatively affected by the coal phase-out (Task Force, 2019b).

Table 4-14 Regional distribution of coal production and coal capacity

Region	Share of coal production	Share of coal capacity
British Columbia	44%	-
Alberta	*41%*	*66%*
Saskatchewan	*15%*	*16%*
Nova Scotia	*1%*	*13%*
New Brunswick	-	*5%*
Manitoba	-	1%

Source: (Government of Canada, 2020)

Two coal mines and three power stations are located in Saskatchewan, where coal is important for local identities: "some communities attribute their entire history to the industry" (Task Force, 2019b). This may explain local resistance to phasing out coal and financial support for CCS technologies from regional governments (Bennett, 2018; Task Force, 2019b; Wingrove, 2016). New Brunswick, where coal has a long legacy, has already undergone several decades of significant decline of the coal industry (Task Force, 2019a).

Figure 4-3 Map of coal-fired generating stations and thermal coal mines in Canada

Source: (Task Force, 2019a)

Alberta may be facing the largest barriers to phasing out coal: the majority of Canadian coal mines and coal plants are located here (Task Force, 2019b). Only one of the mines produces coal for exports and may thus continue operating despite a national coal phase-out (Task Force, 2019b). Alberta also accounts for 13% of Canada's total electricity demand and 37% of its GHG emissions even though only 9% of the population live there due to a large share of carbon intensive industries (Bankes, 2018; Keller et al., 2018). Nevertheless, in 2015, Alberta announced its commitment to phasing out coal by 2030 and pledged to compensate affected companies, workers, municipalities and first nations (Geddes & Gencsü, 2019; Government of Alberta, 2020a, 2020b; Hussey & Jackson, 2019). These transition payments had been recommended by a hired consultant (Bankes, 2018; Bellefontaine, 2016). They are financed from carbon emission payments of industrial emitters (Bellefontaine, 2016). The companies benefitting from the compensation scheme were Capital Power and Atco, which aimed at a higher compensation payment (Kent, 2018) even though only few coal plants will retire: 14 out of 18 units operating at the time are to be converted to gas (Hussey & Jackson, 2019).

4.5.1.3 Coal phase-out policy

In 2017, Canada co-founded the PPCA (Government of Canada, 2019c; PPCA, 2020a). The phase-out is enforced through a performance standard of 420 tonnes CO_2 per GWh of electricity produced with which utilities have to comply by 2030 (Canadian Environmental Protection Act, 1999; PPCA, 2020a). This is designed to phase out conventional, unabated coal power, allowing only units equipped with CCS technology to operate (Canadian Environmental Protection Act, 1999; PPCA, 2020a). Natural gas plants also comply with the standard (PPCA, 2020a). Nova Scotia is negotiating with the national government to enter into an equivalency agreement which may alter the regional implementation of the coal phase-out (Canadian Labour Congress, 2019; Task Force, 2019b). Some welcome the phase-out as compatible with the Paris Agreement (Schindler, 2019) but others criticize it as it seems to encourage the conversion to gas rather than renewables (Cottig & Potter, 2018; Harrahill & Douglas, 2019; Schindler, 2019). However, regional policies in the electricity sector support the increased deployment of wind power, for instance in Alberta and Saskatchewan (Watson & Parashar, 2020).

The Canadian government launched a Just Transition initiative in November 2018 which established transition centres in coal communities in Alberta and provided funding for a geothermal power station in Saskatchewan (Government of Canada, 2019a). To further support affected actors and communities in coal regions, the government launched the 11-person Task Force on Just Transition for Canadian Coal Power Workers and Communities (further: Task Force) in 2018 (Government of Canada, 2019a; PPCA, 2020a). The Task Force visited affected communities, organized public engagement sessions and met stakeholders (Task Force, 2019a). In 2019, two reports were published: one with ten recommendations for a just transition for coal workers and communities and one with impressions from stakeholders gathered throughout the process (Task Force, 2019a, 2019b). The Task Force's mandate only encompassed thermal coal (excluding metallurgical coal mining) (Task Force, 2019a; Wood, 2018). Some have criticized its narrow mandate, focusing on predominantly white and male fossil fuel workers that on average earn higher incomes than accommodation and food service workers in the same highly vulnerable regions who may also be affected by the coal phase-out (Morena et al., 2018; Piggot et al., 2019).

4.5.2 Compensation cost of the Canadian coal phase-out

4.5.2.1 RQ1: What are the avoided emissions of the coal phase-out?

Avoided emissions of the Canadian coal phase-out policy are estimated at 149.7 MtCO_2. As emissions are avoided over 14 years, as the phase-out was announced in 2017 and assuming its end in 2030, this avoids on average 10.7 MtCO_2 per year, 7.2% of total emissions in 2018 which amounted to 572 MtCO_2 (IEA, 2020a).

4.5.2.2 RQ2: How high are the compensation costs of the coal phase-out?

Costs of the Canadian coal phase-out are estimated between $266.6mln and 2,151.2mln. The lower boundary includes pledges of the federal government fixed in the federal budgets 2018 and 2019 and allocated to support the national coal phase-out (Department of Finance, 2018, 2019). The upper boundary additionally includes compensation for Alberta's coal companies, workers and communities, pledged and payed by the Albertan regional government (Government of Alberta, 2016). Even though these are not costs to the national government, they constitute part of the total cost of phasing out coal in Canada. Additionally, the upper boundary includes payments pledged by the Canadian government for support of coal phase-outs in other countries, through financially supporting the PPCA and through contributing to the World Bank's Energy Transition and Coal Phase-out programme (Government of Canada, 2019c; PPCA, 2020a).

Table 4-15 Total and relative costs, upper and lower boundaries, in USD2018mln

Type of cost	Lower boundary	Upper boundary
Total	$270mln	$2,200mln
Total/avoided MtCO_2	$1.8mln	$14mln
Total/worker	$0.08mln	$0.6mln
Total/year	$19mln	$150mln

Sources: Cost/worker considers direct employees of coal mines and coal plants (Task Force, 2019a). Cost/year is calculated over 14 years from the announcement in 2017 until completion by 2030 (PPCA, 2020a).

4.5.2.3 RQ3: How are the compensation costs allocated among actors and purposes?

In the 2018 budget, the national government announced $43.5mln to support skills development for workers and economic diversification activities for communities in the West and Atlantic region to adapt to the transition to a low-carbon economy, completing the work of the Task Force (Department of Finance, 2018). The money is administered by Western Economic Diversification Canada (WD) and Atlantic Canada Opportunities Agency (ACOA), which for instance established two transition centres in Forestburg and Castor, Alberta, providing training programs, entrepreneurial development services and more to former coal miners (Government of Canada, 2019a; Government of Canada, 2019b). Some of these investments are listed in Table 4-16.

Table 4-16 Example projects supported through the Canadian Just Transition fund

Beneficiary	Project
Hanna Learning Centre (HLC)	Establish a business hub and concierge centre for business enquiries and entrepreneurship support
County of Paintearth No. 18	Support business ecosystem development and hire transition staff
United Steel Workers ASM #1595	Hire a transition coordinator to support laid-off workers

Source: (Western Economic Diversification Canada, 2019)

The federal budget 2019 includes the creation of a $190.5mln infrastructure fund to be starting in 2020/2021 to "support priority projects and economic diversification in impacted communities" (Department of Finance, 2019). Specific projects to be supported by this fund have not yet been named to the knowledge of the author. In 2019, the federal government also announced $32.5mln funding for alternative technologies by supporting the establishment of Canada's first geothermal power facility in the coal region Saskatchewan (Government of Canada, 2019b).

The Albertan regional government had also pledged $52.7mln to support coal workers (Government of Alberta, 2020a; Task Force, 2019a). Workers were able to apply for money until they found re-employment or, at a certain age, until retirement (Government of Alberta, 2020b). They could also apply for relocation assistance, tuition vouchers for skills training or for career counselling services (Government of Alberta, 2020b). Coal communities, municipalities and first nations in Alberta were supported with $6.5mln to support their structural development (Government of Alberta, 2020a). Finally, the regional government supported coal companies with $1,468.4mln (Government of Alberta, 2016).

4.5.2.4 Limitations: Possible effects of international finance, co-benefits, double counting on results

The effect of international finance on the costs of phasing out coal in Canada is estimated as small since Canada seems to be a donor rather than a receiving country of international support for coal phase-outs. Double counting of pledged compensation is not very likely regarding compensation for workers which would not have occurred without a coal phase-out. However, support for alternative technologies such as geothermal, or infrastructure projects, may have been planned in advance of the coal phase-out. Co-benefits such as reduced health and environmental costs are likely to occur in Canada. The Canadian government estimates that the acceleration of the phase-out of unabated coal power will avoid $3.8bln between 2019 and 2055 (PPCA, 2020a).

4.6 Germany

4.6.1 Background information

Table 4-17 Background information Germany

Capacity-related indicators		Cost-related indicators	
Functioning of government	12/12	Share of coal in electricity supply	37%
GDP/capita (USD)	47,600	Installed MW coal capacity	47,400
GDP (total) (USD bln)	4,000	Domestic coal production (ktoe)	37,600
		Coal dependence	49%
		Nr of workers in coal sector	35,600

Sources: (FreedomHouse, 2020; Global Energy Monitor, 2020; IEA, 2020d; Jewell et al., 2019; Vazquez-Hernandez et al., 2018; World Bank, 2020i, 2020c), installed MW coal from 2020, FoG from 2019, all other data from 2018. Data at 10% accuracy, for precise values see Appendix 1.6.

4.6.1.1 German energy system and coal sector

Coal played an important role during the recovery of Germany after World War II, as hard coal mining and the associated heavy industry arguably enabled the economic miracle and helped reintegrate Germany in the international community through the European Coal and Steel Community (ECSC) (Herpich et al., 2018; Oei, Brauers, & Herpich, 2019; Oei, Brauers, Herpich, et al., 2019; Reitzenstein et al., 2020). Over time, hard coal faced competition from alternative electricity sources such as oil and natural gas (Herpich et al., 2018). Hard coal production increased until 1958 when the demand for domestic coal decreased due to low oil prices and cheaper foreign coal (Herpich et al., 2018). Government subsidies could not counter this as the ECSC demanded a market based price for coal (Herpich et al., 2018), leading to a sectoral crisis and mine closures (Zechensterben) (Reitzenstein et al., 2020). This together with increasing automatization led to decreasing employment opportunities in the coal sector (Herpich et al., 2018; Reitzenstein et al., 2020).

The coal and steel industry, workers' unions and politicians formed a powerful network, supporting subsidies for the coal sector which were implemented since 1968 (Herpich et al., 2018; Vögele et al., 2018). Towards the public, subsidies were justified through the importance of coal for supply security and as a gateway into international affairs (Herpich et al., 2018; Heyen, 2011; Reitzenstein et al., 2020) despite rising concerns about health effects of air pollution, acid rain and its effects on forests (Waldsterben) and later concerns over climate change (Renn & Marshall, 2016). Public concern was however more focused on the safety of nuclear (Renn & Marshall, 2016). Government support for hard coal mining continued in the 1990s through the coal penny charged to electricity consumers, which was deemed unconstitutional in 1994 (Rentier et al., 2019; Vögele et al., 2018). However, other subsidies remained and in 2000, Germany payed the largest hard coal subsidies of all OECD countries (Rentier et al., 2019). A majority of hard coal production was situated in the Ruhr area, which was particularly affected by the decline of the industry.

Electricity production from renewables had also been supported by the government and increased since 1990 (Herpich et al., 2018; Reitzenstein et al., 2020; Rentier et al., 2019; Vögele et al., 2018). Renewables were also more economically competitive and favoured under climate change measures promoted by the EU (Renn & Marshall, 2016; Vögele et al., 2018). This affected more expensive hard coal more than lignite, which was regarded as a more economically competitive domestic electricity source (Herpich et al., 2018; Reitzenstein et al., 2020; Renn & Marshall, 2016; Rentier et al., 2019; Vögele et al., 2018). In 2011 the government announced the *Energiewende*, which had three major components: nuclear phase-out, the reduction of fossil fuel consumption and an increase in projected energy efficiency (Renn & Marshall, 2016). Though the *Energiewende* supported the growth of renewables, it did not succeed in significantly declining the consumption of coal, especially lignite (Reitzenstein et al., 2020; Renn & Marshall, 2016).

Instead, coal remained an important part of the German electricity system especially in the context of the nuclear phase-out (Herpich et al., 2018; Reitzenstein et al., 2020). Additionally, coal technology was readily available, flexible compared to gas, well integrated into the current energy regime and a regionally important employer (Heyen, 2011; Vögele et al., 2018). In 2018 coal supplied 37% of electricity in Germany (see Table 4-17), generated from approximately 21GW installed lignite and 24 GW hard coal capacity (Oei, Brauers, Herpich, et al., 2019). Hard coal in Germany faces more economic pressure than lignite, as hard coal plants have far higher fuel costs (Oei, Brauers, Herpich, et al., 2019). Due to the merit order, which is based on the marginal cost of electricity and thus typically topped by renewables, the wholesale electricity price is driven down by the increased deployment of renewables (Oei, Brauers, Herpich, et al., 2019). Coal plant owners thus planned to decommission some plants before the end of their useful life, leading to stranded assets (Oei, Brauers, Herpich, et al., 2019). The government implemented a stand-by-reserve that paid utilities to maintain these power plants to guarantee installed coal capacity (Oei et al., 2020; Reitzenstein et al., 2020). RWE, Vattenfall and EPH subsidiaries received €1.6bln over seven years (Reitzenstein et al., 2020; Vögele et al., 2018).

Hard coal mining ended in December 2018 due to the EU-wide prohibition of mining subsidies (Argus Media, 2019a; Deutsche Welle, 2020; Galgóczi, 2019; Oei, Brauers, & Herpich, 2019). Domestic lignite for electricity generation however remains competitive, with support for lignite extraction focusing on exemptions from payable royalties (Vögele et al., 2018). Germany remains the biggest lignite producer worldwide (Oei et al., 2020). Lignite mines and power plants in the Western Rhineland are owned and operated by RWE, and those in federal states of former East Germany by the Czech company EPH through various subsidiaries (Oei, Brauers, Herpich, et al., 2019). RWE is largely owned by regional municipalities that hold 23% of its shares (Rentier et al., 2019; Vögele et al., 2018). RWE and E.On have reacted to the decreased profitability of their conventional coal fleet by separating it from their core business and forming new subsidiaries (Vögele et al., 2018). Uniper, a new subsidiary of E.ON, is the owner of the new Datteln 4 coal block of 1.1GW which is to be connected to the grid in 2020 (Oei, Brauers, Herpich, et al., 2019).

Germany is the largest single contributor to EU CO_2 emissions at 22%, leading to increasing international pressure to reduce emissions (Deutsche Welle, 2020; Reitzenstein et al., 2020). The decline of German GHG emissions stalled since 2014 and many expect Germany to fail their 2020 emission reduction targets (Oei, Brauers, Herpich, et al., 2019). Even though phasing out coal will not single-handedly enable Germany to reach its targets (Heinrichs & Markewitz, 2017), reaching them is not possible if coal use does not decrease (Oei et al., 2020). Politicians were long divided on the issue of coal: while some prioritize remaining a climate leader, others fear that a phase-out will lead to higher electricity prices and resistance from voters (Reitzenstein et al., 2020). This hesitance was arguably accelerated as Germany is a coordinated market economy where many decisions are made through strategic interaction and non-market relations between government, companies and workers' unions, leading to a "carbon lock-in" (Harrahill & Douglas, 2019; Heyen, 2011; Rentier et al., 2019; Vögele et al., 2018). For instance, mineworkers' union leaders are typically part of the social democrat party (SPD) and regularly became members of federal and state parliaments allowing direct political influence (Heyen, 2011; Rentier et al., 2019; Vögele et al., 2018). Changing prioritization of political goals and public attitudes led to coal losing some stakeholder support (Vögele et al., 2018).

4.6.1.2 German coal regions: Rhineland and Lusatia

4.6.1.2.1 Past regional coal declines

Two transitions away from coal occurred in the previously, spanning several regions: the phase-out of hard coal mining in the Ruhr area in Western Germany, and the phase-down of lignite mining in Eastern Germany after the reunification (Herpich et al., 2018). The reason for the decline in hard coal mining in West Germany was the low economic competitiveness of domestically produced compared to imported coal. Additionally, the gradual mechanisation of the sector led to a decline in job availability (Herpich et al., 2018; Oei, Brauers, & Herpich, 2019). Even though a powerful network of coal supporters such as industry and workers' unions successfully lobbied for the protection of domestic production through state subsidies since the 1960s, economic drivers and EU regulation prohibiting subsidies for uneconomic coal mines led to the decision in 2007 to phase-out hard coal mining by 2018 (Herpich et al., 2018; Mavrogenis, 2018; Oei, Brauers, & Herpich, 2019). Even though German lignite mining was relatively cost effective in an international comparison, the competition between Eastern and Western mines after reunification led to a decline of lignite mining in the East (Herpich et al., 2018).

The decision to phase out hard coal mining in the Ruhr region included the commitment that this should be "socially acceptable" (Mavrogenis, 2018) and was negotiated with the regional mining company RAG, trade unions and state governments of Nordrhein-Westfalen (NRW) and Saarland (Zinecker et al., 2018). Since the beginning of the decline of the coal sector in the Ruhr area in the 1960s, government support focused on improving local infrastructure, education institutions and social services. In the 1980s, subsidies increasingly focused on supporting and maintaining the coal industry (Harrahill & Douglas, 2019; Herpich et al., 2018; Reitzenstein et al., 2020). Protests in 1986 however led to a more regionally focused, small-scale and dialogue-based approach developed together with several stakeholders, and policies started to focus on economic diversification and attracting new businesses (Harrahill & Douglas, 2019; Herpich et al., 2018; Reitzenstein et al., 2020). In the Ruhr this approach initially met strong resistance by the coal industry when utilities refused to sell the land they owned (ground lock), whereas it worked well in the Saarland where the mining company was state-owned (Oei, Brauers, & Herpich, 2019). Support for the declining hard coal mining industry and affected actors and regions was granted by the EU until 2022, and support for "inherited time-limited liabilities" until 2029 (State Aid SA.24642(N 708/2007), 2011).

Lignite mining regions in Eastern Germany had arguably even greater difficulties recovering from the decline of the local industry than hard coal regions in the former West, as they were more rural, structurally weak and more dependent on lignite mining than coal regions in West Germany (Herpich et al., 2018; Reitzenstein et al., 2020). The difference in productivity between mines in the East and West led to a significant and sudden decrease of the industry and job losses in the East (Herpich et al., 2018; Reitzenstein et al., 2020). Here, state support focused on compensations for workers through early retirement schemes and retraining measures as well as support for the domestic coal industry to enable a more structured decline (Herpich et al., 2018; Reitzenstein et al., 2020). This also coincided with other state support for economic development in Eastern Germany after reunification but this was often rather ad-hoc and arguably not well planned and utilized (Herpich et al., 2018). Coal regions both in former East and West Germany received support from EU structural funds, for instance the European Regional Development Fund (ERDF), starting around 2000 (Herpich et al., 2018)

4.6.1.2.2 Current coal regions

Figure 4-4 shows the three main lignite regions: Rhineland, central German coalfields and Lusatia. In all three remaining lignite coalfields, coal extraction and employment in the coal sector has declined since 1990 (Oei, Brauers, Herpich, et al., 2019) and these previous experiences lead to scepticism and concerns regarding further decline (Oei et al., 2020; Reitzenstein et al., 2020). Part of these experiences, focusing on the Ruhr region, are described in section 2.3.2.5.

Figure 4-4 Locations of coal-fired power plants and coalfields in Germany

Source: (Oei, Brauers, & Herpich, 2019)

Lusatia, which has undergone a major transition during the German reunification, seems particularly vulnerable to effects of the coal phase-out (Stognief et al., 2019). Lusatia has few other industrial sectors than lignite mining and has been called an "industrial monoculture" (Oei, Brauers, Herpich, et al., 2019). GDP per capita is far below the national average, and the unemployment rate is almost twice the national average (Oei, Brauers, Herpich, et al., 2019; Oei et al., 2020). Infrastructure and connectedness to other regions are limited and the aging population, results in a constantly declining workforce and shortage of skilled workers (Oei, Brauers, Herpich, et al., 2019; Oei et al., 2020).

The Rhineland and central German coalfields are better positioned to undergo structural change. In the Rhineland, lignite contributes 0.6% to the regional value creation, compared to 4% in Lusatia (Oei, Brauers, Herpich, et al., 2019; Oei et al., 2020). Next to coal, the Rhineland has a highly developed service sector and a diversified industrial sector, an active start-up scene, and an above-average GDP per capita, and unemployment only slightly above the national average (Oei, Brauers, Herpich, et al., 2019; Oei et al., 2020). The smallest remaining lignite field is the central German coalfield, where the sector provides 0.4% of regional value added (Oei, Brauers, Herpich, et al., 2019; Oei et al., 2020). GDP per capita is below the national average but higher than in Lusatia, the economy is more diversified and there is also better infrastructure than in Lusatia (Oei, Brauers, Herpich, et al., 2019). However, the unemployment rate is comparatively high and, similarly to Lusatia, emigration of the younger population led to an overall aging population (Oei, Brauers, Herpich, et al., 2019).

4.6.1.3 Coal phase-out policy

Support for renewable electricity sources and phasing out hard coal subsidies was not sufficient to achieve a coal phase-out in Germany due to social friction around job losses and the power of incumbents who formed networks with politicians and workers' unions (Oei et al., 2020). Disagreement within the government on whether and how to phase out coal may explain the decision to launch the Commission on Growth, Structural Change and Employment (dt: Kommission 'Wachstum, Strukturwandel und Beschäftigung, further: the Commission) in June 2018 (Agora Energiewende & Aurora Energy Research, 2019; Commission, 2019; Reitzenstein et al., 2020), which some have highlighted as another example of decision-making through strategic interaction (Rentier et al., 2019).

The Commission included 28 members, among them representatives of industry, academia, environmental groups and workers unions as well as three non-voting members from the ruling parties (Reitzenstein & Popp, 2019; Wacket, 2019). Three unions were represented: the Industrial Workers' Union for Mining, Energy and Chemistry (IGBCE), the United Services Trade Union (ver.di) and the German Trade Union Confederation (DGB) (Just Transition Centre, 2019). Whereas IGBCE pushed for a slow coal phase-out, DGB historically demonstrated a strong commitment to climate action and just transition approaches (Reitzenstein et al., 2020). Several business associations were represented, of which some supported an accelerated coal phase-out whereas others pushed for delaying the decline (Reitzenstein et al., 2020). Regional governments were not represented but aimed to exert influence through connections with represented actors to promote a longer transition period and federal compensation schemes (Reitzenstein et al., 2020).

The task of the Commission was to develop a strategy to phase out coal-fired power generation, allowing Germany to meet its emission targets and to outline policy measures that consider negatively affected coal mining regions (Agora Energiewende & Aurora Energy Research, 2019; Commission, 2019; Reitzenstein & Popp, 2019). The final report of the Commission, submitted in early 2019, proposed a gradual coal phase-out through a planned termination of individual mines and power plants, finalized latest in 2038 or optionally in 2035 (Commission, 2019) The support schemes the Commission envisioned for affected actors have largely been translated into two parallel (draft) laws: A law on financial compensation for affected groups has been finalized by the government in 2019, the law implementing the coal phase-out is still debated. Both are foreseen to come into force in 2020 (Entwurf Strukturstärkungsgesetz Kohleregionen, 2019; Entwurf Kohleausstiegsgesetz, 2020).

The coal phase-out law stipulates that electricity generation from coal will be prohibited for individual power plants, enabling a gradual decline of installed coal capacity (Bundesregierung, 2020). The timeline and amount of compensation for lignite plant retirement was negotiated with power plant owners (Bundesregierung 2020). Hard coal plants will be phased out exclusively through auctions where power plant owners can submit bids for compensation until 2023 (Bundesregierung, 2020). Between 2024 and 2027, there will be both auctions and forced power plant closures by law, and from 2027 all hard coal plant closures will be mandated by law (Bundesregierung, 2020). Plants closing due to legal mandates will not receive any compensation (Bundesregierung, 2020). Latest from first January 2039 any electricity generation from hard and brown coal is prohibited (Bundesregierung, 2020). Before then, it is prohibited to build new coal plants, except if the emission permit for the plant was retrieved before 29 January 2020 (Bundsregierung, 2020). This exception is designed for Datteln 4 to come online in summer 2020 (Wettengel, 2020).

After delays due to disagreements (Wehrmann, 2019), the draft coal phase-out law was approved by the gathering of ministers and the cabinet (Bundesregierung) (Ferdinand, 2019). It is now discussed and potentially amended by the parliament and then approved by the regional governments (Ferdinand, 2019). Environmental NGOs and some researchers find that the phase-out is too slow and retires older coal plants too late (Buck, 2020; Europe Beyond Coal, 2020a; Kirschbaum, 2019; Vaughan, 2019). The plan is arguably not in line with the Paris agreement which would require a coal phase-out latest by 2030 or 2035 (Oei, Brauers, Herpich, et al., 2019; Reitzenstein & Popp, 2019). Studies suggest that most Germans, even those living in coal regions, support accelerating the coal phase-out even at additional cost (Heinrichs et al., 2017; Kirschbaum, 2019; Rinscheid & Wüstenhagen, 2019; Vaughan, 2019). Some also worry that running remaining power plants at higher capacity or importing electricity generated from coal may increase emissions (Pahle et al., 2019). Another concern is that, notwithstanding existing plans to increase the share of renewables to 65% in 2030, gas will become the "backup power of choice" and that this may lead to a new fossil lock-in (Heinrichs & Markewitz, 2017; Vaughan, 2019). Others are content with the plan (Nienaber & Hansen, 2020), whereas yet others, mainly utilities and coal union members, consider it "too hasty" and hope for a further extension and possibly additional compensation (Argus Media, 2019a; Nienaber & Hansen, 2020; Vaughan, 2019).

4.6.2 Compensation cost of the German coal phase-out

4.6.2.1 RQ1: What are the avoided emissions of the coal phase-out?

If coal is phased out by 2035, estimated avoided emissions are 1,524.6 $MtCO_2$. If it is phased out until 2038, the estimate is 1,301.3 $MtCO_2$. This calculation assumes that Datteln 4 comes online in 2020 and operates until the phase-out date in line with current statements. Assuming that, depending on the final year of coal use, emissions are avoided over 16 or 19 years, the phase-out on average avoids 95.3 $MtCO_2$ (by 2035) or 68.5 $MtCO_2$ (by 2038). This amounts to 14% (2035) and 10% (2038) respectively compared to total CO_2 emissions in 2018, which were 683 Mt (IEA, 2020d). Another estimate of avoided emissions reaches a slightly lower estimate of around 1000 $MtCO_2$ by 2038 compared to BAU (Agora Energiewende & Aurora Energy Research, 2019).

4.6.2.2 RQ2: How high are the compensation costs of the coal phase-out?

Costs of the German coal phase-out are estimated between $47,531.1mln and $80,100.5mln. The lower boundary includes payments pledged in the draft laws on coal phase-out and structural development. Additionally, some infrastructure measures have been discounted to account for the possibility of double-counting: these measures had been previously planned under the Federal traffic route plan (dt.: Bundesverkehrswegeplan) 2030 and are now to be accelerated through funds mobilized for structural development under the coal phase-out policy (BMWi, 2019) (see Appendix 2.7 for a complete list of individual project names, costs and sources). Estimated value of double counted projects is $2,968.8mln.

The upper boundary does not consider double counting, as it is uncertain which potential projects will be accelerated under the final structural development law. Additionally, this estimate includes compensation for electricity consumers which is paid in case electricity prices rise as a result of the coal phase-out (Bundesregierung, 2020). It is uncertain whether this will occur, and if so by how much electricity prices will rise. The estimate used here was derived from the Commission's recommendation of compensating electricity users with €2bln annually starting in 2023 (Commission, 2019). Finally, the upper boundary includes remaining costs of the hard coal phase-out which stretch until 2029 (State Aid SA.24642(N 708/2007), 2011).

Table 4-18 Total and relative costs, upper and lower boundaries, in USD2018mln

Type of cost	Lower boundary		Upper boundary	
	2035	**2038**	**2035**	**2038**
Total	$47,500mln		$80,100mln	
Total/avoided $MtCO_2$	$31mln	$37mln	$53mln	$62mln
Total/worker	$1.3mln		$2.3mln	
Total/year	$2,800mln	$2,400mln	$4,700mln	$4,000mln

Sources: Cost/worker considers direct employees of both coal mines and coal plants (Vazquez-Hernandez et al., 2018) Cost/year is calculated over 17 years from announcement in 2019 to 2035 and over 20 years until 2038 (Commission, 2019; PPCA, 2019a). Data at 10% accuracy.

Another study quantifying the cost of the coal phase-out estimates €63-93 bln (Agora Energiewende & Aurora Energy Research, 2019). They include €40bln for structural aid for affected coal regions, compensation to utilities and employees as determined in the draft coal phase-out law, and €3-4bln for the cancellation of CO_2 certificates. Additionally, they assume compensation of electricity consumers between €16-32bln.

4.6.2.3 RQ3: How are the compensation costs allocated among actors and purposes?

Brown coal companies receive $3,629.2mln. RWE receives about 60% of this compensation, and EPH receives about 40% (BBC, 2020; Entwurf Kohleausstiegsgesetz, 2020; Wettengel, 2020). Both RWE and EPH pushed for compensation and stated that the current amounts may not cover their costs (Argus Media, 2018; Nienaber & Hansen, 2020; Vaughan, 2019). After compensations were announced, share prices of E.ON and RWE rose significantly (Buck, 2020; Nienaber & Hansen, 2020; Parkin, Jennen, & Wilkes, 2020; Wilkes & Parkin, 2019). Compensation is payed to companies to alleviate additional costs of premature retirement of power plants, for instance due to renaturation, restructuring of the business and electricity marketing (Entwurf Kohleausstiegsgesetz, 2020).

Hard coal companies that close before 2027 can receive compensation during auctions (Entwurf Kohleausstiegsgesetz, 2020). The maximum amount for hard coal compensation is estimated at $1,668.6mln (€2-2.2bln) (Kammer, 2020; Parkin, Jennen, & Donahue, 2020). This compensation is not tied to specific purposes. Additional funding of $150.2mln has been announced to support the transition of CHP power plants from coal to gas (Entwurf Kohleausstiegsgesetz, 2020). Eligible workers receive a one-time payment to alleviate negative effects through unemployment (dt.: Anpassungsgeld). The draft law specifies that this money will be payed directly from the federal budget to an estimated 40,000 eligible workers and maximum spanning $4,171.5mln between 2020 and 2048 (Entwurf Kohleausstiegsgesetz, 2020).

Energy intensive companies and private electricity consumers may be compensated for rising electricity prices due to the coal phase-out, starting in 2023 (Entwurf Kohleausstiegsgesetz, 2020). The Commission recommended this compensation to be up to €2bln per year (Commission, 2019), leading to an estimated total of $26,697.4mln between 2023 and 2038. As several studies expect electricity prices to rise (Agora Energiewende & Aurora Energy Research, 2019; Oei, Brauers, Herpich, et al., 2019; Qussous et al., 2019), it seems likely that this cost will arise.

The affected regions Saxony-Anhalt, Saxony, NRW and Brandenburg will receive $11,680.1mln to support their transition away from coal (Entwurf Strukturstärkungsgesetz Kohleregionen, 2019). Saxony-Anhalt receives 12%, Saxony 25.2%, Brandenburg 25.8% and NRW 37%

(Entwurf Strukturstärkungsgesetz Kohleregionen, 2019). This is envisioned for buying and improving land to attract new companies, improve regional roads and railways, support social services such as child- and healthcare, improve digitalization, research infrastructure and others (Entwurf Kohleausstiegsgesetz, 2020). $21,691.7mln has been earmarked to further support the same regions by financing individual projects (Entwurf Strukturstärkungsgesetz Kohleregionen, 2019). Some projects are proposed by regions and municipalities, some are developed by the federal government including planned research institutions, investment in cultural infrastructure, establishing federal offices in the affected regions to create employment opportunities and support for roads and railways that are under national responsibility (Entwurf Strukturstärkungsgesetz Kohleregionen, 2019).

4.6.2.4 Limitations: Potential effects of international finance, co-benefits and double counting

Considering the financial capacity of the German government, the potential effect of international finance may be limited here in comparison to other countries. Nevertheless, German regions benefit from the ESIF. Lusatia, for instance, annually receives €35-40mln (Oei, Brauers, Herpich, et al., 2019). Germany is also eligible for payments from the Just Transition Fund, currently estimated at €877mln (European Commission, 2020).

Double counting was partly quantified for the case of Germany. This study considers double counting as visible through the draft law where previously planned projects which are to be accelerated through the coal phase-out are specified (Entwurf Strukturstärkungsgesetz Kohleregionen, 2019). However, depending on the methodology used and the insights into political planning and decision-making processes, assessments of double counting may differ: according to a local politician of the Lusatia region, only one fourth of the money pledged is additional expenditure, while three fourth are reallocated from existing funds (Machowecz, 2019).

Finally, co-benefits of the coal phase-out such as reducing environmental and health costs, avoiding re-settlements of villages in mining regions (Oei, Brauers, Herpich, et al., 2019) and supporting alternative sectors and regional development have not been quantified here and may affect a long-term cost-benefit analysis of phasing out coal.

5 Discussion

Section 5 compares and discusses the results presented for individual countries throughout section 4. Section 5.1 compares and discusses results of all six case studies. It is structured in the same order as each of the individual country sections: section 5.1.1 compares the context of all analyzed countries, and sections 5.1.2, 5.2.3 and 5.1.4 discuss each of the three RQs respectively. Sections 5.2 and 5.3 discuss these results in the context of prior research on the feasibility of phasing out coal and on MAC of other emission mitigation policies respectively. Section 5.4 revisits the concept of distributional costs in light of the results of this thesis.

5.1 Comparative presentation and discussion of results

5.1.1 National contexts of coal phase-outs

This section comparatively presents context-dependent factors which may help to better understand why compensation costs differ across countries. According to Jewell et al. (2019) and Jewell and Cherp (2020), the political feasibility of climate mitigation measures depends on their costs and on the capacity of relevant actors to bear these costs.

Table 5-1 shows that all countries in this study that committed to phasing out coal have relatively high Functioning of Government (FoG) index scores, between 9 and 12 out of 12 (see also section 5.2 for a discussion in context with prior literature), indicating relatively high institutional capacity of these governments. Remarkably, Slovakia and Greece have lowest FoG, lowest GDP and lowest GDP per capita out of all analyzed countries. This indicates lowest financial capacity to compensate affected actors.

Table 5-1 Capacity-related indicators

Country	FoG	GDP/capita (current USD)	GDP (current USD bln)
Slovakia	9/12	19,400	110
Greece	9/12	20,300	220
Finland	12/12	50,200	280
Spain	11/12	30,400	1,400
Canada	12/12	46,200	1,700
Germany	12/12	47,600	4,000

Sources: See respective country section or Appendix 1. GDP and GDP/capita data from 2018; FoG: Slovakia-2019, Greece-2019, Finland-2016, Spain-2018, Canada-2017, Germany-2019.

Even though Slovakia and Greece score similarly regarding capacity-related indicators, they differ considerably regarding cost-related indicators, as Table 5-2 shows. Most notably, the Greek coal mining sector is much larger than the Slovakian coal mining sector considering the amount of domestically produced coal and the degree of dependence on imported coal. Greece also has a much larger share of coal in the electricity mix and a higher number of employees in the coal sector. The only country with a higher share of coal in the electricity mix than Greece is Germany. Germany is also the country with most MW coal capacity and the highest number of workers in the coal sector. This may lead to higher resistance to and costs of phasing out coal. However, Germany has much higher financial capacity than Greece (see Table 5-1).

Table 5-2 Cost-related indicators

Country	Share of coal in electricity mix	Currently planned and installed coal capacity (MW)	Domestic coal production (ktoe)	Coal dependence	Directly employed workers in coal sector
Slovakia	11%	690	370	86%	2,700
Greece	34%	4,400	4,400	5%	6,500
Finland	9%	1,900	0	79%	1,100
Spain	14%	9,900	780	91%	6,700
Canada	8%	9,800	27,746	0%	3,490
Germany	37%	47,400	37,615	49%	35,600

Sources: See respective country section or Appendix 1. Coal capacity for 2020, all other data for 2018.

Canada, Slovakia and Finland may face lower barriers against phasing out coal, as the share of coal is about 10% in the respective electricity mixes. Especially Finland, which is the only studied country that does not produce coal domestically, can be expected to face lower resistance because the number of affected groups is lower: there are less workers in the coal sector and no workers or companies in coal mining.

Aside from Finland, all countries analyzed here have highly coal-dependent regions where the coal mining industry is located. Slovakia, Greece and Germany, where hard coal mining was phased out in 2018, currently only mine lignite for domestic electricity generation. Until the recent phase-out of all coal mining in 2019, Spain mined both hard coal and lignite of which 15% were used for steel production and the rest for electricity generation. Canada still mines both metallurgical and thermal coal and exports large amounts of coal, which is why its overall coal dependency is 0% even though it also imports some coal. After Canada, Greece is the second-least coal dependent country at 5%, where all domestically mined lignite is used for electricity generation. In all countries analyzed here besides Canada, coal power phase-out also means coal mining phase-out. Even though there may be some decline of coal mining activities, metallurgical coal, exported coal and coal for use in CCS coal plants may still be mined. This also means that, as most countries show coal dependence above 50%, the coal mining industry in the countries where they import coal from may be affected.

5.1.2 RQ1: Avoided emissions of the coal phase-out pledges

Among the analyzed countries, Finland was the first to commit to phasing out coal in 2016. Slovakia pledges to phase out coal the fastest, which may be possible as it has the lowest amount of installed MW coal capacity and substitution of phased out coal is guaranteed through nuclear deployment (Filcak et al., 2018; Oravcová, 2019). Germany plans phasing out coal over the longest time period, but also avoids most emissions, almost ten times above the second highest avoided emissions, Canada. Germany and Greece avoid most emissions relative to national CO_2 emissions: on average, the Greek coal phase-out avoids 13 $MtCO_2$ per year, 20.6% of total CO_2 emissions in 2018. Germany avoids 10-14% of national CO_2 emissions in 2018 on average per year.

Table 5-3 Phase-out timeline, avoided emissions (Mt) and total CO_2 emissions 2018 (Mt)

Country	Phase-out timeline	Avoided CO_2 emissions	Average annual avoided emissions	Total CO_2 emissions 2018
Slovakia	2019-2023	8.4	1.7	32
Greece	2019-2028	130	13	62
Finland	2016-2029	23	1.8	44
Spain	2018-2030	38	3.2	250
Canada	2017-2030	150	11	570
Germany	2019-2035/38	1,300-1,500	69-95	680

Sources: see respective country sections. Avoided emissions indicated at 10% accuracy.

5.1.3 RQ2: Compensation costs of the coal phase-outs

There are different approaches to phasing out coal. Slovakia and Spain seem to mostly rely on market-based policies such as the subsidy removal and carbon pricing rather than scheduling mine and power plant closures, which is the approach taken by Greece and Germany. In Germany, this schedule precedes a ban of coal-fired power generation, which is implemented in Finland without prior scheduling and negotiations. Canada is the only country in which CCS technology seems to be considered by the coal phase-out: the performance standard leading to the closure of conventional power plants allows only coal plants with CCS to generate electricity.

Table 5-4 Types and compensation costs of national coal phase-out policies

Country	Type of coal phase-out policy	Compensation cost (USD2018mln)
Slovakia	Phase-out of coal mining subsidies, carbon pricing	\$76mln-\$2,500mln
Greece	Gradual mine and power plant closures, carbon pricing	\$51mln-\$220mln
Finland	Ban of coal	\$76mln
Spain	Phase-out of coal mining subsidies	\$420mln-\$1,900mln
Canada	Performance standard	\$270mln-\$2,200mln
Germany	Gradual mine and power plant closures, Ban of coal power generation	\$48,000mln-\$80,000mln

Sources: see respective country section. Compensation costs indicated at 10% accuracy.

As Figure 5-2 shows, Germany, Spain and Slovakia pay most per avoided ton of CO_2 emissions compared to Greece, Canada and Finland. Compensation costs per ton of avoided CO_2 emissions range from \$0.4 to \$305. The cost of one ton of carbon was about \$13 on average over the last five years, at its lowest at \$5.6 (2016) and highest at \$25 (2019) (Markets Insider, 2020), indicated by the shaded area in Figure 5-1 (For a table indicating cost of carbon for each year between 2015 and 2019, see Appendix 3). In Spain and Germany, compensation cost per ton of avoided CO_2 emissions is currently higher than paying the price for emitting one ton of carbon, and in Slovakia, it far exceeds the cost of emitting carbon. In Greece, where the cost of carbon has been mentioned as one driver of phasing out coal, compensation cost is much lower than costs of emitting carbon.

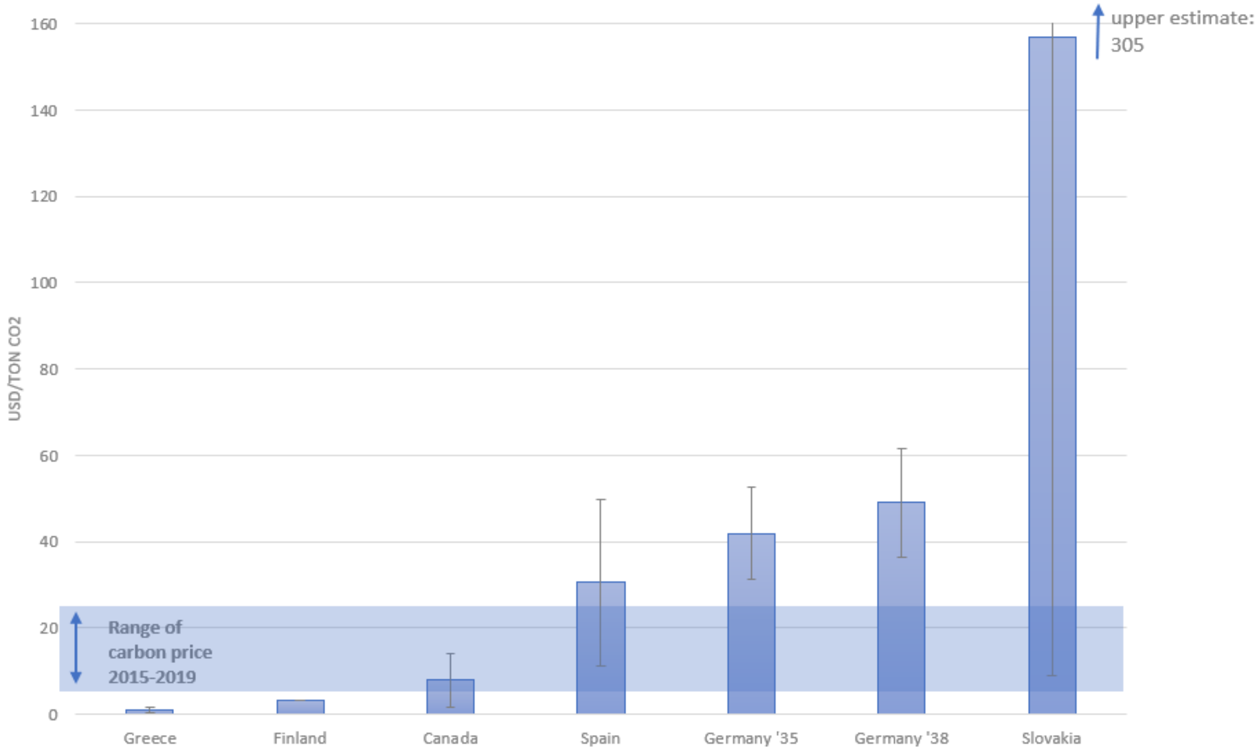


Figure 5-1 Compensation costs per avoided ton CO_2 emissions

Sources: Median of upper and lower boundary estimates with error bars: own calculations. The positive error for Slovakia is not shown as it far exceeds the other values. Carbon price in EU ETS: (Markets Insider, 2020).

As Figure 5-1 shows, Canada, Spain and Germany bear similar compensation costs per ton of avoided CO_2 emissions at approximately the same order of magnitude, between about $10 and $50. Among these three countries, Canada faces the lowest compensation costs per avoided ton CO_2 emissions. The national significance of coal in Canada is limited due to its relatively low share in the national electricity mix (below 10%). In Spain, share of coal in the national electricity mix is almost double that in Canada, and in Germany it almost five times higher. However, coal is of high regional importance for instance in Alberta. The Albertan regional government has thus carried part of the costs of the national coal phase-out through compensating affected actors. Additionally, the type of coal phase-out policy implemented in Canada may reduce compensation requests of coal companies: The phase-out is implemented through a performance standard which enables switching to gas or retrofits of power plants with CCS technology without mandating the closure of individual plants such as in Germany. Additionally, the coal mining industry in Canada is not as strongly affected as in Spain and Germany, which may further reduce requests for compensation.

Nevertheless, the Canadian government compensates similar societal groups as Spain and Germany, including laid-off workers, coal communities, and compensating companies for investments in substituting coal power. Similarly to Canada, Spanish utilities are less likely to demand compensation as the coal phase-out is not realized through individually mandated power plant closures but through techno-economic drivers causing utilities to retire coal plants. Compensation costs of phasing out coal in Spain mainly stem from compensating affected workers that are well-organized in influential workers' unions and have historically received relatively high government support. Spanish coal mining regions, similarly to German coal regions, are characterized through a lack of economic diversification, a lack of infrastructure and a local identity centered around coal mining, leading local actors to resist phasing out coal. Total compensation costs in Germany are much higher than in Spain and Canada. In addition to compensating coal regions and workers, Germany compensates coal companies and electricity consumers. Through the much higher avoided emissions, costs per ton of avoided emissions are in the same order of magnitude but higher than in Spain and Canada. Even though total costs of compensation in Spain and Canada are similar, Canada avoids a much higher amount of CO_2 emissions, it bears lower compensation costs per avoided ton CO_2.

Slovakia bears comparatively high costs per avoided ton of CO_2 emissions. One reason may be the low amount of avoided emissions, as much less coal capacity is phased out than in any of the other countries: Slovakia is the only country phasing out less than 1GW installed coal capacity. In addition to coal power, all coal mining is phased out in Slovakia. A non-government owned company, HBP, holds the monopoly of coal mining. HBP is thus likely to demand compensation. Indeed, it is the only beneficiary of lower boundary compensation costs. Even at comparable total lower boundary costs to Finland, lower boundary costs per avoided ton CO_2 emissions are similar to Spain. Another reason for large compensation costs per avoided ton CO_2 emissions is high upper boundary cost estimate. Additional upper boundary costs mainly stem from compensation pledged to the structurally disadvantaged coal region Upper Nitra. This estimate is highly uncertain as none of this money has been earmarked in the official budget. It is likely that part of this money will be payed through international finance, thus not imposing costs on the national government.

In contrast to these four countries, Finland faces comparatively low costs per ton avoided CO_2 emissions, even though it has the second lowest amount of avoided emissions. Finland only compensates district heating companies using coal who accelerate their coal phase-out process by supporting the instalment of alternative technologies. One explanation for this relatively low amount of compensation, even though utilities had demanded additional compensation, could be the relatively long phase-out period which aims to "reconciliat[e] different kinds of public and private interests" (Ministry of Economic Affairs and Employment, 2019b). another explanation may be that there are less affected actors than in other countries, as there is no coal mining industry and coal plants are not located in remote regions with low regional GDP and high unemployment rate as in Germany and Spain, for instance. Instead, Finnish coal plants are in larger cities which indicates that it is more likely for laid-off workers to find new jobs.

Finally, Greece yields surprising results: The size and importance of the national coal mining industry and the regional dependence of Western Macedonia on the coal sector leads to large expected compensation payments to companies, workers and communities. However, the total lower boundary estimate shows lowest total compensation costs of all countries. Additionally, Greece has the lowest compensation cost per avoided ton CO_2 emissions (see Figure 5-1). This may be explained through the low financial capacity of the government, which may not be able to afford larger compensations for affected actors. Quantifying compensation payed for through international finance may increase observed compensation costs. Additionally, the energy utility PPC is government-owned, which may mean that the government absorbs some of the costs of phasing out coal through its ownership without a transparent compensation scheme. Only mining communities are compensated as expected.

Two other metrics to compare costs across countries are compensation costs per worker and compensation costs per installed GW coal capacity (see Table 5-5). For both these metrics, lower boundary costs in Germany are highest. Only Slovakia faces higher upper boundary costs per GW than Germany. This can be explained as the upper boundary estimate for Slovakia is highly uncertain and potentially includes international finance, and installed coal capacity in Slovakia is almost 70 times lower than in Germany.

Table 5-5 Cost per worker and per GW coal capacity

Country	Cost (USDmln) per worker		Cost (USDmln) per GW	
	Lower boundary	Upper boundary	Lower boundary	Upper boundary
Slovakia	0.03	1	110	3,700
Greece	0.01	0.03	11	50
Finland	0.07	0.07	40	40
Spain	0.06	0.3	43	190
Canada	0.08	0.6	27	220
Germany	1.3	2.3	1,000	1,700

Sources: own calculations; see individual country sections and Appendix 1. Cost per GW indicated at 10% accuracy.

Figure 5-2 shows that Finland, Greece, Canada and Spain roughly pledge between 0.01% and 0.1% of their national GDP as compensation payments to coal phase-outs. The lower boundary cost estimate for Slovakia also falls within this range. Germany pledges to pay most at above 1% of its national GDP, even for its lower boundary cost estimate. Even though this needs to be corroborated through further research, this may indicate that most countries are likely to spend between 0.01% and 0.1% of their national GDP on phasing out coal. This allows to infer how much money governments may be willing to spend on phasing out coal based on their national GDPs. This may be compared with an estimate of the potential distributional costs of phasing out coal in the given country, thus allowing for an estimate of the political feasibility of phasing out coal in the respective context.

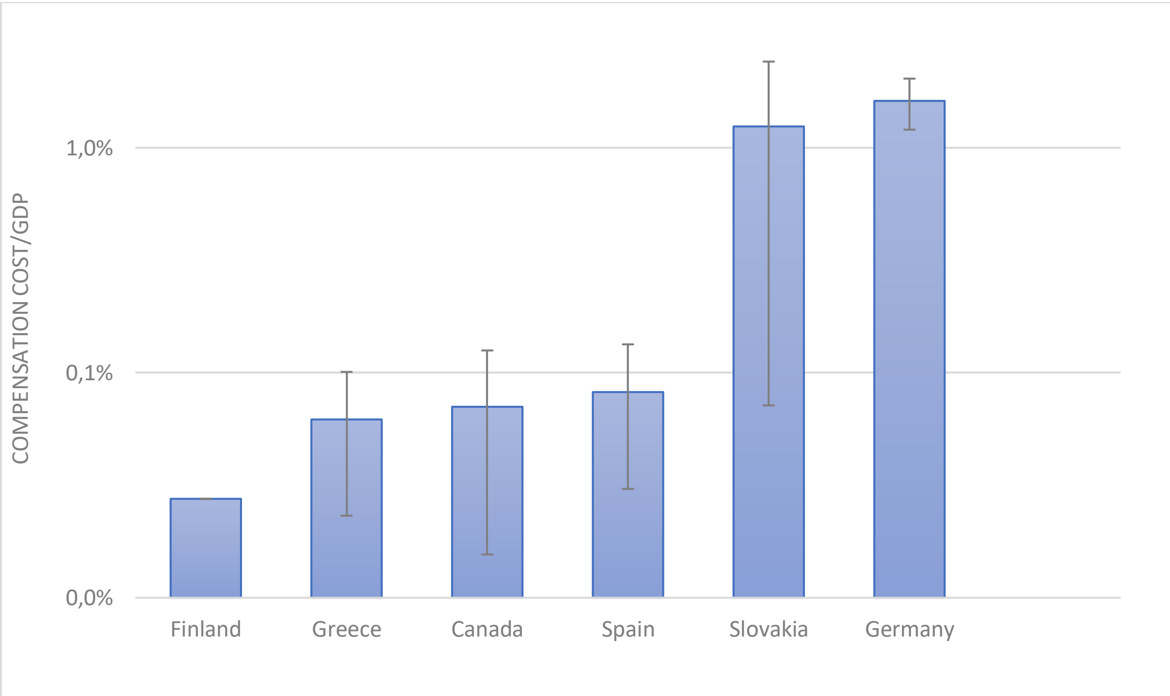


Figure 5-2 Compensation cost relative to GDP

Sources: own calculations. National GDP in 2018 derived from World Bank database, for sources see Appendix 1.

5.1.4 RQ3: Allocation of compensation among actors and purposes

Almost all compensation schemes allocate money to support the structural development of affected communities, including regional governments and municipalities. The only exception is Finland, which does not mine coal and where power plants are located in cities and not rural areas with structural development issues. Workers directly benefit from compensation only in Spain and Germany. In Slovakia, money pledged to companies is meant for alleviating negative effects on workers, and in Canada and Greece, funding is used to support re-employment and retraining opportunities for laid off workers.

Table 5-6 Beneficiaries and purposes of compensation schemes

Country	Primary beneficiaries	Purpose	Compensation (USD2018mln)
Slovakia	Mining company HBP	Early retirement payments for workers, additional underground safety work, reclamation and recultivation of land, compensate for lost profits	$82mln
	Local companies, regional administration/government	Support structural development of Upper Nitra region	Up to $2,500mln
Greece	Mining communities (Florina and Kozani regions), municipality of Megalopolis	Support economic diversification and improvement of infrastructure, local agriculture and tourism sectors, retraining workers	$51mln-$220mln
Finland	CHP companies	Support renewables and alternative technologies for heat generation	$76mln
Spain	Workers	Early retirement schemes, retraining schemes, job bourse	$84mln
	Coal regions	Supporting structural development in regions	$110mln-$510mln
	Companies	Investments in renewables	$130mln
		Compensation of coal mining companies for exceptional costs including payments to workers and production losses	$960mln
Canada	Communities (by national government and Albertan regional government)	Providing retraining programs, entrepreneurial development services and other projects to support economic diversification	$230mln-$240mln
	Companies (only in Alberta)	Covering exceptional costs, ensuring electricity supply	$1,500mln
	Workers (only in Alberta)	Bridge to re-employment or retirement, skills training, career counselling	$53mln
Germany	Companies	Renaturation of land, restructuring of business, electricity marketing	$5,300mln
	Workers	Bridging until re-employment or retirement	$4,200mln
	Communities: regional governments and individual actors proposing projects	Improving land for use of new companies, improve roads and railways, improve digital infrastructure, establish research centres etc.	$33,400mln
	Electricity consumers	Relieve higher electricity prices	Up to $26,700mln

Sources: see respective country sections or Appendix 2

5.2 Comparison with prior research on political feasibility of phasing out coal

Table 5-1 shows that all countries in this study have relatively high FoG scores ranging from 9 to 12 (out of 12), similar to the findings of Jewell et al. (2019) who find that the probability of countries joining the PPCA increases at higher FoG scores. Figure 5-3 shows this: the probability of joining the PPCA is higher than 50% above the dashed line. For five out of the six countries analyzed in this thesis, Jewell et al. (2019) find that they are relatively likely to join the PPCA at a probability of at least 5%, indicated by the shaded area in Figure 5-3. Greece is the only country outside the shaded area, i.e. the probability of Greece joining the PPCA based on their FoG and share of coal in electricity supply is below 5%.

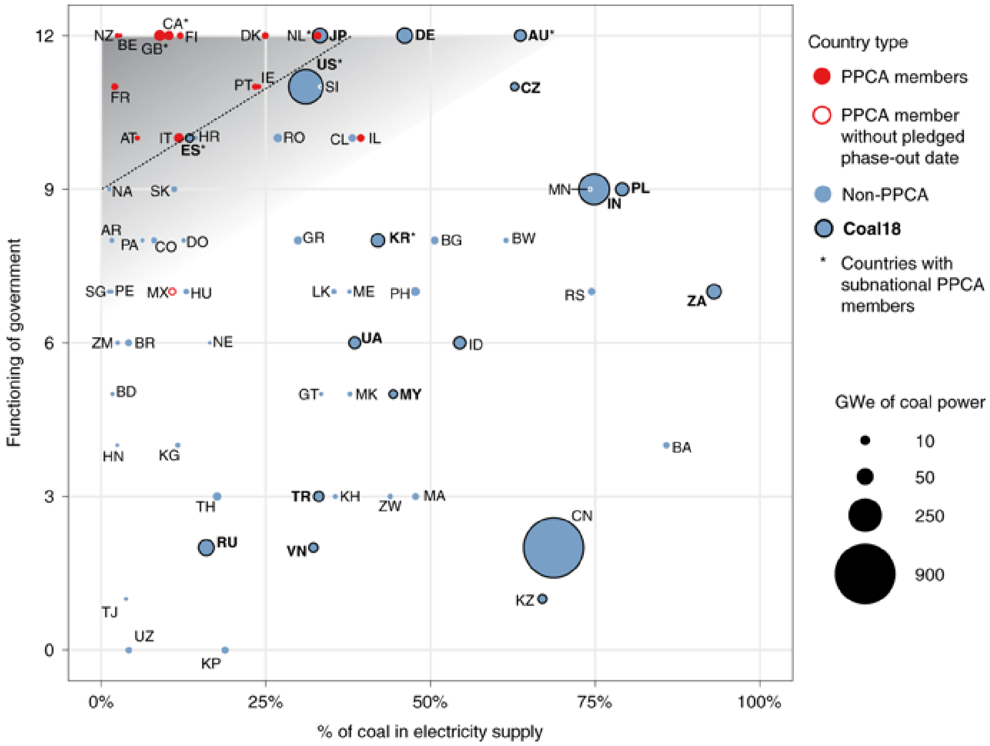


Figure 5-3 Functioning of Government index and share of coal in electricity generation in PPCA members, Coal18 and other countries

Source: Jewell et al., 2019

One reason for Greece joining the PPCA in 2019 may be increased institutional capacity, as Greece reached a FoG score of 9 in 2019, compared to 8 in 2018 (FreedomHouse, 2020). However, even at a FoG score of 9, the probability of Greece joining the PPCA barely reaches 5% as Greece would be situated directly at the border of the shaded area in Figure 5-3. Several other factors may partly explain why Greece joined the PPCA: first, the Greek coal plant fleet is ageing, with the average age of coal plants in Western Macedonia currently at 31 years (Buzatu, 2019; Popp, 2019). Many of these plants do not comply with current EU emissions standards (Ganbold & Megaritis, 2019): several plant's permits to operate were recently revoked by the Greek Supreme Administrative Court after a legal challenge was filed by national environmental organizations (Arbinolo, 2019; Burton, 2019; ClientEarth, 2020). It would require significant investments to retrofit remaining plants so they may operate in the future (Ganbold & Megaritis, 2019; Rovolis & Kalimeris, 2019). In combination with rising prices of emitting one ton of carbon under the EU ETS, coal power thus becomes less and less economically competitive and Greek coal plants operate at losses (Koutantou & Fenton, 2019; Koutantou & Harvey, 2019; Popp, 2019).

Notwithstanding relatively low government capacity and relatively high share of coal in the electricity mix, which indicate barriers of a Greek coal phase-out, economic and political drivers such as rising carbon prices, tighter emissions standards, and requirements for retrofits may be among the several factors enabling the Greek coal phase-out.

5.3 Comparison with prior research on MAC of other emission mitigation measures

Coal phase-out policies are not included among the MAC calculations of policy measures presented by Gillingham and Stock (2018). The comparability of traditional MAC calculations and compensation costs per ton of avoided CO_2 emissions as done by this study is however limited: traditional MAC calculate aggregate costs of emission mitigation measures to society without considering how these costs are distributed among different actors, i.e. who pays for emission mitigation. In this thesis, I calculate part of the costs of coal phase-out policies to a specific actor: costs of compensating affected actors to governments.

Nevertheless, comparatively presenting these results makes it possible to reflect on the cumulative costs of climate mitigation measures. Figure 5-4 thus includes both MAC of climate mitigation policies collected by Gillingham and Stock (2018) and compensation costs per avoided ton CO_2 emissions derived through this thesis. It shows that compensation costs of phasing out coal to governments are on average lower than aggregate costs of other emission mitigation measures to society. However, implementing a coal phase-out may require the implementation of other measures, such as increasing deployment of solar PV. As Figure 5-4 shows, the aggregate costs of solar PV subsidies to society seem to be very high (see arrow on the right of Figure 5-4). This indicates that in addition to compensation costs for phasing out coal, governments (and other societal actors) may face costs of substituting coal powered electricity, which may be much higher than the costs of coal phase-outs themselves.

Understanding and being able to compare the distributional costs of different climate mitigation measures may thus provide a new way of ranking climate mitigation measures. Heinisch et al. (2019) for instance conceptualize abatement cost as job losses which require consequent compensation schemes and raise the question of whether the German coal phase-out minimizes these costs compared to other emission mitigation measures. Additionally, in Figure 5-4, the aggregate costs of a gasoline tax seem lower than average compensation costs of phasing out coal and may thus be prioritized by decision makers. The French example of implementing a carbon tax however illustrates the significance of distributional rather than aggregate costs for the feasibility of climate mitigation measures: public resistance due to (perceived) distributional effects of the French carbon tax halted this measure from becoming implemented (Douenne & Fabre, 2020).

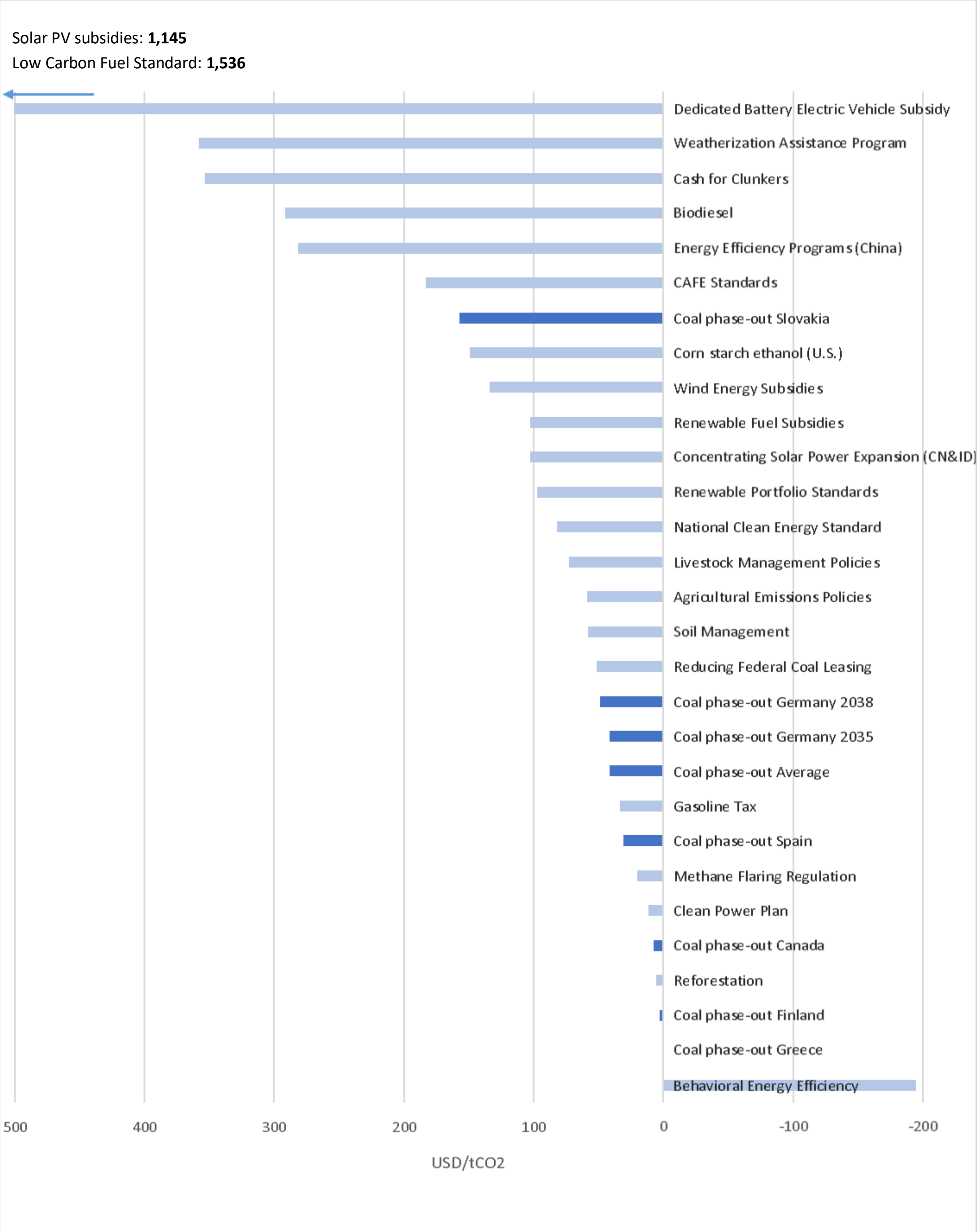


Figure 5-4 Static MAC of emission mitigation policies compared to compensation costs of phasing out coal

Sources: (Gillingham & Stock, 2018 and own calculations).

5.4 Distributional cost and feasibility of phasing out coal

The example of the French carbon tax shows that considering the distributional costs of climate mitigation policies may help decision makers implement these policies by anticipating and addressing resistance due to disproportionally distributional costs. In this thesis, I calculate compensation costs as a proxy of the distributional costs of phasing out coal. Costs of phasing out coal affect the coal industry, workers in coal mining and power generation, coal-dependent regions and potentially electricity consumers if electricity prices rise as a result of the coal phase-out. These groups have been compensated by different countries as shown in Table 5-7, with only Germany compensating all groups of affected actors: workers, companies, communities/regions and electricity consumers. All other countries compensate only some of these groups.

One reason for differences between compensation costs may be that not all groups are equally affected and require compensation in all contexts. Another reason may be, however, that not all groups may have the power to demand compensation for their incurred costs. In Germany, for instance, it seems that decision making institutions enable access to decision making processes for different groups such as the coal industry, miners' unions and regional governments, which are also relatively powerful (Herpich et al., 2018; Rentier et al., 2019; Vögele et al., 2018). Yet another reason may be that governments have different financial capacities, and not all may be able to reallocate money away from other purposes to compensate affected actors. In Greece, for instance, the coal mining industry, including its workers, and the coal region Western Macedonia are strongly affected by the coal phase-out. Compensation costs are nevertheless relatively low, which may be explained through limited financial capacity.

Compensation costs thus do not precisely represent distributional costs. However, they are empirically observable and may serve as an indication of the extent to which national governments need to redistribute the costs of climate mitigation measures to implement them in their national context. Being able to estimate distributional costs of climate mitigation policies in different contexts is significant for academics and practitioners: For academics, it may advance understanding of costs of emission mitigation to national governments. Gaining a more accurate estimate of costs of emission mitigation to governments may advance understanding the political feasibility of climate mitigation as these costs can be compared to governments' capacities, for instance governments of major coal consuming countries such as India or China.

For practitioners and decision makers, being able to estimate distributional costs of climate mitigation measures may help to include both an ideological "fairness" dimension and an instrumental feasibility dimension in their decisions: First, considering the distribution of costs of climate mitigation measures across different societal groups may help understand which groups face largest costs, for instance poorer compared to higher income groups. Depending on their understanding of "justice" or "fairness", decision makers may then aim to distribute the costs of emission mitigation more equitably among different societal groups. Second, decision makers may be able to estimate potential resistance among certain societal groups against emission mitigation measures with disproportionally distributional costs and may thus compensate affected actors with the aim of limiting this resistance.

6 Conclusion

6.1 Summary

Rapid decarbonization necessary to mitigate climate change requires ambitious policies. Among many climate mitigation measures, model-derived decarbonization pathways indicate that phasing out conventional coal-powered electricity generation is one of the most urgent measures to be realized latest by mid-century. Even though existing tools such as IAMs or MAC calculations improve the understanding of the techno-economic feasibility of climate mitigation measures by estimating the aggregate costs of these measures to society overall, they do not consider how these costs are distributed among different societal groups and the social and political barriers these distributional costs may cause. If distributional costs are too large and perceived as unjust by societal groups, these groups may resist decarbonization. Not considering distributional costs of climate mitigation measures may thus limit the feasibility of climate mitigation measures or create an inequitable distribution of these costs across society.

Coal phase-outs, for instance, may impose costs on the coal industry, workers in the coal sector and regions where coal mining and electricity generation from coal are centered and regional economies are thus dependent on the jobs and tax revenue provided by this industry. As phasing out coal is pertinent to mitigating climate change, several national governments have committed to phasing out coal and compensating the disproportionally affected actors of these policies. The costs of these compensation schemes, even though they do not directly measure distributional costs, are relevant to understanding the significance of distributional costs for the feasibility of climate mitigation measures: they indicate the extent to which governments need to interfere to redistribute the costs of climate mitigation. This requires financial and institutional capacity, as governments need to collect money from citizens and companies (for instance through taxation) and redistribute this to negatively affected actors of coal phase-outs.

This compensation cost is only part of the total cost governments need to bear to phase out coal. Other costs may include, for instance, substituting coal through renewables technologies. Even though total costs of coal phase-outs to governments could not be measured within the scope of this thesis, calculating compensation costs provides a first step towards understanding total costs of emission mitigation. Better understanding the costs of emission mitigation measures also provides further insight into their political feasibility, which is a function of the costs of specific measures to specific actors. The cost of compensation schemes to phase out coal have not yet been assessed by existing literature.

This thesis thus focuses on compensation cost of phasing out coal, one of the most urgent climate mitigation measures, to governments. To compare compensation costs of phasing out coal to different governments, this thesis borrows from the widely used MAC concept, calculating compensation cost per avoided ton of CO_2 emissions due to the respective coal phase-out. To this end, this thesis analyzes six countries implementing coal phase-outs coupled with compensation schemes: Slovakia, Greece, Finland, Spain, Canada and Germany. It uses a structured, focused comparison methodology, systematically applying three RQs to each of the selected countries:

1. What are the avoided emissions of the coal phase-out pledges?
2. How high are the compensation costs of the coal phase-outs?
3. How are compensation costs allocated among different actors and purposes?

This thesis finds that Canada, Germany and Spain face similar costs of climate mitigation measures, roughly about \$10 to \$50 per avoided ton CO_2 emissions. All countries besides Finland, where there is no coal mining industry, compensate affected coal communities. To this extent, compensation costs may indicate distributional costs which are comparatively low in Finland, which does not need to compensate affected coal communities. However, compensation costs do not directly mirror distributional costs: Greece, for instance, bears lowest compensation costs per avoided ton CO_2 emissions and lowest total compensation cost even though there is an important domestic coal mining sector, centred in a structurally disadvantaged, coal-dependent region (Western Macedonia), indicating high distributional costs. The low observed compensation costs may be explained through the low financial government capacity preventing higher compensation and government ownership of the energy company, through which the government may absorb costs of phasing out coal without transparent compensation.

This thesis also finds that most governments pledge between 0.01% and 0.1% of their national GDPs to phasing out coal. These may be especially relevant for major coal consuming countries with potentially high distributional costs of phasing out coal and comparatively low government capacity, similar to Greece: it is likely that in the absence of techno-economic and political drivers which pushed Greece towards phasing out coal, governments may not be able to afford financially compensating affected actors to enhance the feasibility of phasing out coal. Considering that in addition to phasing out coal other emission mitigation measures need to be implemented to achieve rapid decarbonization, money that governments spend on phasing out coal becomes unavailable for the implementation of these additional measures.

The findings of this thesis thus enable initial insights into the distributional costs of phasing out coal and how this may affect the political feasibility of decarbonization. However, limitations of this study need to be considered before drawing conclusions. For instance, there are data limitations such as possible changes to governments' plans and draft laws that may occur as further negotiations take place before their implementation. Potential changes may be larger due to the current COVID-19 crisis which may restrain governments' budgets more than would have been otherwise the case and thus impact their financial capacity. This study did not systematically assess the role of international finance for the observed compensation costs. Additionally, this thesis only analyzed countries with transparent compensation schemes, not considering factors enabling countries to phase out coal without compensating negatively affected actors. Finally, this thesis did not quantify co-benefits of phasing out coal or of projects funded through the compensation schemes.

6.2 Recommendations for future research

These limitations lead to recommendations for future research.

First, future research may consider the influence of international finance such as EU structural development finance on compensation costs of phasing out coal. This may provide insights into the feasibility of phasing out coal in coal-intensive countries such as Greece with limited financial capacity. Similarly, coal phase-out policies of countries without (transparent) compensation schemes should be analyzed towards understanding which context-dependent factors and capacities enable governments to phase out coal at a presumably lower cost. This may help to understand in which contexts compensation costs occur (or not) and how large they are. Considering the implications of compensation costs for the feasibility of phasing out coal, i.e. that they indicate necessary government capacity to redistribute costs across societal groups, leads to further recommendations for future research: it is most important that major coal consuming countries such as China or India phase out coal-powered electricity considering global CO_2 emissions mitigation. Previous findings indicating necessary government capacity to compensate affected actors may be compared and contrasted with governments' capacities in these major coal consuming countries.

Even though understanding compensation costs provides an indication of necessary government capacity to implement emission mitigation measures, total costs to governments may include additional costs such as substituting for coal-fired electricity, among others. Future research may thus further investigate costs of phasing out coal to understand how much it costs governments to achieve climate mitigation targets. Additionally, phasing out coal is not the only climate mitigation measure necessary to achieve rapid decarbonization. Understanding costs of different climate mitigation measures may help to understand cumulative cost of decarbonization pathways and thus more realistically assess to which extent governments' financial capacity allows for the implementation of model-derived decarbonization pathways.

Finally, in addition to the feasibility of climate mitigation, compensation schemes may affect the fairness of these pathways by more equitably distributing the costs of climate mitigation. However, there are many different conceptualizations of the "justice" or "fairness". Questioning whether compensation or "just transition" schemes really make climate mitigation fairer is beyond the scope of this thesis. This has been partially addressed by existing research, but may be further studied in the future, as questions remain: who benefits from these schemes? One study analyzing the Canadian compensation scheme argued that mostly middle-aged, white men who work in mines and power stations and receive an above-average pay are compensated, whereas women working in the service industry (restaurants for instance) and earn significantly lower wages are not compensated. Another question may be who effectively pays for the compensation? For instance, is the money allocated to compensation derived from public taxes, or from specific pools such as revenues from ETS auctions? Who effectively designs compensation schemes?

6.3 Policy recommendations

Even though there are limitations to the findings of this thesis, some policy recommendations can be drawn from the existing insights.

Generally, this thesis encourages policymakers to consider distributional costs of climate policies in their decision making practices. Even if a quantitative assessment of the distributional effect on different groups may not be possible for each climate mitigation measure, decision makers may conduct analyses of potentially affected groups prior to implementing the measure and based on this design policy responses such as compensation schemes. This may help to prevent largely disproportional distributional effects of policies on more vulnerable groups and may limit resistance against such policies Examples such as the French carbon tax suggest that this is not always the case.

This thesis also recommends to policymakers that they aim to consider several climate mitigation measures necessary for decarbonization simultaneously: As Figure 5-4 shows, there is a large amount of available measures, each with its own costs. Considering different necessary climate mitigation measures simultaneously may help to channel government resources more efficiently. For instance, if part of the total costs of phasing out coal is to compensate regional governments for a lack of tax revenue due to company closures and job losses, these payments may be directed at enhancing low-carbon businesses and sectors in these same regions.

Considering costs to governments of necessary climate mitigation measures may help governments to better assess whether reaching national climate targets is feasible based on the estimated costs of these measures and the available government budget.

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Appendix

1 Capacity- and cost-related indicators and sources

1.1 Slovakia

Capacity-related indicators		**Source**	**Cost-related indicators**		**Source**
GDP/capita (USD)	19,442.7	(World Bank, 2020k)	Share of coal in electricity supply	11%	(IEA, 2020f)
Functioning of government	9/12	(FreedomHouse, 2020)	Installed MW coal capacity	693	(Global Energy Monitor, 2020)
GDP (total) (USD bln)	105,904.6	(World Bank, 2020e)	Domestic coal production (ktoe)	366	(IEA, 2020)
			Coal dependence	86%	(Jewell et al., 2019), Supplementary data 1
			Nr of workers in coal sector	2700	(Vazquez-Hernandez et al., 2018)

1.2 Greece

Capacity-related indicators		**Source**	**Cost-related indicators**		**Source**
GDP/capita (US$)	20,324.4	(World Bank, 2020j)	Share of coal in electricity supply	34%	(IEA, 2020e)
Functioning of government	9/12	(FreedomHouse, 2020)	Installed MW coal capacity	3,775	(Global Energy Monitor, 2020)
GDP (total) (USD bln)	218,031.8	(World Bank, 2020d)	Domestic coal production (ktoe)	4,375	(IEA, 2020e)
			Coal dependence	5%	(Jewell et al., 2019), Supplementary data 1
			Nr of workers in coal sector	6500	(Vazquez-Hernandez et al., 2018)

1.3 Finland

Capacity-related indicators		**Source**	**Cost-related indicators**		**Source**
GDP/capita (USD)	50,152.3	(World Bank, 2020h)	Share of coal in electricity supply	9%	(OSF, 2019a)
Functioning of government	12/12	(FreedomHouse, 2020)	Installed MW coal capacity	1,885	(Global Energy Monitor, 2020)
GDP (total) (USD bln)	276,743.1	(World Bank, 2020b)	Domestic coal production	0	(IEA, 2020c)

			Coal dependence	79%	(Jewell et al., 2019), Supplementary data 1
			Nr of workers in coal sector	1100	(Vazquez-Hernandez et al., 2018)

1.4 Spain

Capacity-related indicators		Source	Cost-related indicators		Source
GDP/capita (USD)	30,370.9	(World Bank, 2020l)	Share of coal in electricity supply	14%	(IEA, 2020g)
Functioning of government	10/12	(FreedomHouse, 2020)	Installed MW coal capacity	9,859	(Global Energy Monitor, 2020)
GDP (total) (USD bln)	1,419,042	(World Bank, 2020f)	Domestic coal production	779	(IEA, 2020g)
			Coal dependence	91%	(Jewell et al., 2019), Supplementary data 1
			Nr of workers in coal sector	6700	(Vazquez-Hernandez et al., 2018)

1.5 Canada

Capacity-related indicators		Source	Cost-related indicators		Source
GDP/capita (USD)	46,233	(World Bank, 2020g)	Share of coal in electricity supply	8%	(IEA, 2020a)
Functioning of government	12/12	(FreedomHouse, 2020)	Installed MW coal capacity	8,429	(Global Energy Monitor, 2020)
GDP (total) (USD bln)	1,713,341.7	(World Bank, 2020a)	Domestic coal production	27,746	(IEA, 2020a)
			Coal dependence	0%	(Jewell et al., 2019), Supplementary data 1
			Nr of workers in coal sector	3490	(Task Force, 2019a)

1.6 Germany

Capacity-related indicators		Source	Cost-related indicators		Source
GDP/capita (USD)	47,603	(World Bank, 2020i)	Share of coal in electricity supply	37%	(IEA, 2020d)
Functioning of government	12/12	(FreedomHouse, 2020)	Installed MW coal capacity	47,430	(Global Energy Monitor, 2020)
GDP (total) (USD bln)	3,947,620.2	(World Bank, 2020c)	Domestic coal production	37,615	(IEA, 2020d)
			Coal dependence	49%	(Jewell et al., 2019)

			Nr of workers in coal sector	35,600	(Vazquez-Hernandez et al., 2018)

2 Cost of coal phase-outs, broken down to individual posts, and sources

2.1 Slovakia

	Beneficiary	Amount (2018$mln)	Source
Lower boundary	HBP	$75.9mln	(European Commission, 2019)
Upper boundary	HBP	$5.1mln	(European Commission, 2014; Ministry of Economy, 2019)
	Diverse, incl regional governments and companies	$2,474.9mln	(PPCA, 2019; Seban, 2019)

2.2 Greece

	Beneficiary	Amount (2018$mln)	Source
Lower boundary	Mining communities	$50.5mln	(Ministry of Environment and Energy, 2019)
Upper boundary	Mining communities	$169.4mln	(Ministry of Environment and Energy, 2019)

2.3 Finland

	Beneficiary	Amount (2018$mln)	Source
Lower boundary	District heating companies using coal	$76.2mln	(Ministry of Economic Affairs and Employment, 2018, 2019)

2.4 Spain

	Beneficiary	Amount (2018$mln)	Source
Lower boundary	Affected workers in the coal sector	$84.1mln	(Ministerio para la transición ecológica, 2018)
	Coal mining regions	$109.8mln	(Ministerio para la transición ecológica, 2019)
	Renewable energy companies	$129.8mln	(Ministerio para la transición ecológica, 2019)

Upper boundary	Diverse, to be determined by future just transition agreements	$504.6mln	(Ministerio para la transición ecológica, 2019)
	Coal mining companies	$960.3mln	(European Commission, 2016)

2.5 Canada

	Beneficiary	**Amount (2018$mln)**	**Source**
Lower boundary	Workers, communities, local businesses	$43.5mln	(Department of Finance, 2018)
	Diverse (may include workers, local businesses, communities)	$190.5mln	(Department of Finance, 2019)
	Geothermal power plant	$32.5mln	(Department of Finance, 2019)
Upper boundary	Power plant workers	$52.7mln	(Government of Alberta, 2020; Task Force, 2019)
	Communities, municipalities, first nations	$6.5mln	(Government of Alberta, 2020)
	Coal companies	$1,468.4mln	(Government of Alberta, 2016)
	World Bank Energy Transition and Coal Phase-out programme	$356.4mln	(Government of Canada, 2019; PPCA, 2020)
	PPCA secretariat	$0.8mln	(Government of Canada, 2019; PPCA, 2020)

2.6 Germany: costs

	Beneficiary	**Amount (2018$mln)**	**Source**
Lower boundary	Brown coal companies	$3,629.2mln	(Bundesregierung, 2020)
	Hard coal companies	$1,668.6mln	(Bundesregierung, 2020; Kammer, 2020; Parkin, Jennen, & Wilkes, 2020)
	Workers	$4,171.5mln	(Bundesregierung, 2020)
	Regional governments	$11,680.1mln	(Bundesregierung, 2019)
	Diverse (local companies,	$21,691.7mln	(Bundesregierung, 2019)

	government-led projects)		
	Double counted projects	-$2,968.8mln	See table below
Upper boundary	Electricity consumers	$26,697.4mln	(Bundesregierung, 2020; Commission, 2019)
	Hard coal mining companies	$2,903.2mln	(European Commission, 2011)

2.7 Germany: double-counted projects

Project name	**Cost (€2014mln)**	**Cost ($2018mln)**	**Source**	**Last assessed**
B97 Groß Oßnig	7,9	7,0	http://www.bvwp-projekte.de/strasse/B97-G10-BB/B97-G10-BB.html#h1_nutzen	26.05.2020
B97 OU Cottbus (3. BA)	18,3	16,2	http://www.bvwp-projekte.de/strasse/B97-G20-BB/B97-G20-BB.html	26.05.2020
B97 OU Cottbus (A15-B168), 2. BA	30,6	27,1	http://www.bvwp-projekte.de/map_street.html	26.05.2020
B101 OU Elsterwerda	17,1	15,2	http://www.bvwp-projekte.de/strasse/B101-G10-BB/B101-G10-BB.html	26.05.2020
B169 OU Elsterwerda	19,5	17,3	http://www.bvwp-projekte.de/strasse/B169-G30-SN-BB-T5-BB/B169-G30-SN-BB-T5-BB.html	26.05.2020
B169 OU Schwarzheide Ost	9,3	8,2	http://www.bvwp-projekte.de/strasse/B169-G20-BB/B169-G20-BB.html	26.05.2020
B169 OU Plessa	16,2	14,4	http://www.bvwp-projekte.de/strasse/B169-G10-BB/B169-G10-BB.html	26.05.2020
B169 OU Allmosen	7,7	6,8	http://www.bvwp-projekte.de/strasse/B169-G30-BB-T1-BB/B169-G30-BB-T1-BB.html	26.05.2020
B169 OU Lindchen	6,5	5,8	http://www.bvwp-projekte.de/strasse/B169-G30-BB-T2-BB/B169-G30-BB-T2-BB.html	26.05.2020
B169 OU Neupeters-hain Nord	8,2	7,3	http://www.bvwp-projekte.de/strasse/B169-G30-BB-T3-BB/B169-G30-BB-T3-BB.html	26.05.2020
B169 OU Klein Oßnig und OU Annahof/Klein Gaglow	13,4	11,9	http://www.bvwp-projekte.de/strasse/B169-G30-BB-T4-BB/B169-G30-BB-T4-BB.html	26.05.2020

B97 OU Ottendorf-okrilla mit AS	37,6	33,3	http://www.bvwp-projekte.de/strasse/B97-G10-SN/B97-G10-SN.html	26.05.2020
B115 OU Krauschwitz	9,7	8,6	http://www.bvwp-projekte.de/strasse/B115-G10-SN/B115-G10-SN.html	26.05.2020
B156 OU Malschwitz/Niedergurig	6,2	5,5	http://www.bvwp-projekte.de/strasse/B156-G10-SN/B156-G10-SN.html	26.05.2020
B156 OU Bluno	7,1	6,3	http://www.bvwp-projekte.de/strasse/B156-G20-SN/B156-G20-SN.html	26.05.2020
B178 Nostitz - A4 (BA 1.1)	38,8	34,4	http://www.bvwp-projekte.de/map_street.html	26.05.2020
B178 Zittau-Niederoder-witz	32,6	28,9	http://www.bvwp-projekte.de/map_street.html	26.05.2020
A13 AK Schönefeld - AD Spreewald	133,5	118,4	http://www.bvwp-projekte.de/strasse/A13-G10-BB/A13-G10-BB.html	26.05.2020
AD Nossen - AS Pulsnitz	866,3	768,2	https://www.mdr.de/sachsen/ausbau-autobahn-vier-nossen-bautzen-100.html; https://www.medienservice.sachsen.de/medien/news/220910?page=1	26.05.2020
A1 ASK Bliesheim (A61) - AD Erftal (A61)	24,2	21,5	http://www.bvwp-projekte.de/strasse/A1-G20-NW/A1-G20-NW.html	26.05.2020
A1 AD Erftal - AK Köln-West	18,3	16,2	http://www.bvwp-projekte.de/strasse/A1-G30-NW/A1-G30-NW.html	26.05.2020
A52 Ak Mönchengladbach (A61) - Ak Neersen	46,8	41,5	http://www.bvwp-projekte.de/strasse/A52-G11-NW/A52-G11-NW.html	26.05.2020
A57 Ak Köln-N (A1) - AD Neuss-S (A46)	95,7	84,9	http://www.bvwp-projekte.de/strasse/A57-G20-NW/A57-G20-NW.html	26.05.2020
A1 AS Lommersdorf (l115z) - AS (Blankenheim) (B51)	49,6	44,0	http://www.bvwp-projekte.de/strasse/A001-G10-NW-RP-T03-NW/A001-G10-NW-RP-T03-NW.html	26.05.2020
A1 AS Adenau (L10) - AS Lommersdorf (L115z)	126,9	112,5	http://www.bvwp-projekte.de/strasse/A001-G10-NW-RP-T02-NW-RP/A001-G10-NW-RP-T02-NW-RP.html	26.05.2020
A61 AK Meckenheim - AK Bliesheim	31,9	28,3	http://www.bvwp-projekte.de/strasse/A61-G60-NW/A61-G60-NW.html	26.05.2020

A61a AK Wanlo (A61) - AK Mönchengladbach (A52)	80,4	71,3	http://www.bvwp-projekte.de/strasse/A61-G41-NW/A61-G41-NW.html	26.05.2020
A553 AK Köln-Godorf - AD Köln-Lind	300,3	266,3	http://www.bvwp-projekte.de/strasse/A553-G10-NW-T2-NW/A553-G10-NW-T2-NW.html	26.05.2020
B51 Köln/Meschenisch	12,9	11,4	http://www.bvwp-projekte.de/strasse/B51-G50-NW-T2/B51-G50-NW-T2.html	26.05.2020
B56 OU Euskirchen	33,5	29,7	http://www.bvwp-projekte.de/strasse/B56-G30-NW-T1-NW/B56-G30-NW-T1-NW.html	26.05.2020
B56 OU Swissttal/Miel	11,7	10,4	http://www.bvwp-projekte.de/strasse/B56-G30-NW-T3-NW/B56-G30-NW-T3-NW.html	26.05.2020
B56 Jülich - As Düren	32,5	28,8	http://www.bvwp-projekte.de/strasse/B56-G10-NW/B56-G10-NW.html	26.05.2020
B57 OU Baal	10,5	9,3	http://www.bvwp-projekte.de/strasse/B57-G10-NW-T2-NW/B57-G10-NW-T2-NW.html	26.05.2020
B57 OU Gereonsweiler	4,2	3,7	http://www.bvwp-projekte.de/strasse/B57-G10-NW-T1-NW/B57-G10-NW-T1-NW.html	26.05.2020
B59 OU Allrath	5,4	4,8	http://www.bvwp-projekte.de/strasse/B59-G10-NW-T2-NW/B59-G10-NW-T2-NW.html	26.05.2020
B221 OU Scherpenseel	10,4	9,2	http://www.bvwp-projekte.de/strasse/B221-G30-NW/B221-G30-NW.html	26.05.2020
B221 Geilenkirchen - As Heinsberg	11,6	10,3	http://www.bvwp-projekte.de/strasse/B221-G10-NW/B221-G10-NW.html	26.05.2020
B221 OU Unterbruch	33,2	29,4	http://www.bvwp-projekte.de/strasse/B221-G20-NW-T1-NW/B221-G20-NW-T1-NW.html	26.05.2020
B264 OU Golzheim	4,1	3,6	http://www.bvwp-projekte.de/strasse/B264-G10-NW/B264-G10-NW.html	26.05.2020
B265 OU Liblar - OU Hürth/Hermülheim	8	7,1	http://www.bvwp-projekte.de/strasse/B265-G30-NW-T1-NW/B265-G30-NW-T1-NW.html	26.05.2020

B266 OU Mechernich/Roggendorf	6,6	5,9	http://www.bvwp-projekte.de/strasse/B265-B266-G10-NW-T2-/B265-B266-G10-NW-T2-.html	26.05.2020
A44 As Broichweiden - AS Alsdorf	32,5	28,8	http://www.bvwp-projekte.de/strasse/A44-G10-NW/A44-G10-NW.html	26.05.2020
A46 AD Holz AK Neuss-W	82,8	73,4	http://www.bvwp-projekte.de/strasse/A46-G10-NW/A46-G10-NW.html	26.05.2020
B477 OU Niederaußem	12,9	11,4	http://www.bvwp-projekte.de/strasse/B477-G20-NW-T1-NW/B477-G20-NW-T1-NW.html	26.05.2020
B477 Berghein/Rheidt	9,6	8,5	http://www.bvwp-projekte.de/strasse/B477-G20-NW-T2-NW/B477-G20-NW-T2-NW.html	26.05.2020
A14 AS Leipzig-O Ad Parthenaue	26,2	23,2	http://www.bvwp-projekte.de/map_street.html	26.05.2020
Borna-Nord AD A 38/A72	134,4	119,2	http://www.bvwp-projekte.de/map_street.html	26.05.2020
B2 OU Groitzsch/ Audigast	15,5	13,7	http://www.bvwp-projekte.de/strasse/B2-G10-SN-T1-SN/B2-G10-SN-T1-SN.html	26.05.2020
B2 Verlegung bei Zwenckau	11,5	10,2	http://www.bvwp-projekte.de/strasse/B2-G10-SN-T2-SN/B2-G10-SN-T2-SN.html	26.05.2020
B2 OU Hohenossig	6,5	5,8	http://www.bvwp-projekte.de/strasse/B2-G20-SN-T1-SN/B2-G20-SN-T1-SN.html	26.05.2020
B2 OU Wellaune	5,9	5,2	http://www.bvwp-projekte.de/strasse/B2-G20-SN-T4-SN/B2-G20-SN-T4-SN.html	26.05.2020
B7 Verlegung in Frohburg	36,6	32,5	http://www.bvwp-projekte.de/strasse/B7_B180-G10-TH-ST-SN-T1-SN/B7_B180-G10-TH-ST-SN-T1-SN.html	26.05.2020
B87n Leipzig - Landesgrenze	301,4	267,3	http://www.bvwp-projekte.de/strasse/B87-G21-SN-BB/B87-G21-SN-BB.html	26.05.2020
B107 OU Grimma	12,8	11,4	http://www.bvwp-projekte.de/map_street.html	26.05.2020
B169 AS Döbeln-Nord Salbitz	29,6	26,2	http://www.bvwp-projekte.de/strasse/B169-G30-SN-BB-T1-SN/B169-G30-SN-BB-T1-SN.html	26.05.2020
B169 Salbitz	29,3	26,0	http://www.bvwp-projekte.de/strasse/B169-G30-	26.05.2020

			SN-BB-T2-SN/B169-G30-SN-BB-T2-SN.html	
B181 Neu-/Ausbau westl. Leipzig	13,5	12,0	http://www.bvwp-projekte.de/strasse/B181-G10-SN/B181-G10-SN.html	26.05.2020
B186 Verlegung westlich Markranstädt	17,3	15,3	http://www.bvwp-projekte.de/strasse/B186-G10-SN/B186-G10-SN.html	26.05.2020
B6 OU Großkugel	4,7	4,2	http://www.bvwp-projekte.de/strasse/B6-G10-St-T1/B6-G10-St-T1.html	26.05.2020
B6 OU Gröbers	5,1	4,5	http://www.bvwp-projekte.de/strasse/B6-G10-ST-T2/B6-G10-ST-T2.html	26.05.2020
B6 OU Bruckdorf	16,5	14,6	http://www.bvwp-projekte.de/strasse/B6-G10-ST-T3/B6-G10-ST-T3.html	26.05.2020
B80 OU Aseleben	8,8	7,8	http://www.bvwp-projekte.de/strasse/B80-G10-ST/B80-G10-ST.html	26.05.2020
B87 OU Weißenfels (Südtangente)	24,5	21,7	http://www.bvwp-projekte.de/strasse/B87-G10-ST/B87-G10-ST.html	26.05.2020
B87 OU Wethau	37,9	33,6	http://www.bvwp-projekte.de/strasse/B87_B180-G10-ST/B87_B180-G10-ST.html	26.05.2020
B87 OU Naumburg	13,5	12,0	http://www.bvwp-projekte.de/strasse/B87-G20-ST-T1/B87-G20-ST-T1.html	26.05.2020
B87 OU Bad Kösen	76,9	68,2	http://www.bvwp-projekte.de/strasse/B87-G20-ST-T2/B87-G20-ST-T2.html	26.05.2020
B87 OU Taugwitz/OU Poppel - OU gernstedt	4,7	4,2	http://www.bvwp-projekte.de/strasse/B87-G20-ST-T3/B87-G20-ST-T3.html	26.05.2020
B87 OU Eckartsberga	7,7	6,8	http://www.bvwp-projekte.de/strasse/B87-G20-ST-T4/B87-G20-ST-T4.html	26.05.2020
B180 OU Aschersleben/ Süd - Quenstedt	26,2	23,2	http://www.bvwp-projekte.de/strasse/B180-G60-ST/B180-G60-ST.html	26.05.2020
B180 OU Farnstädt	8,4	7,4	http://www.bvwp-projekte.de/strasse/B180-G40-ST/B180-G40-ST.html	26.05.2020
B181 OU Zöschen-Wallendorf - Merseburg	89,3	79,2	http://www.bvwp-projekte.de/strasse/B181-G10-ST/B181-G10-ST.html	26.05.2020

3 Cost of carbon in EU ETS over time

Year	Average cost of carbon (USD)
2015	7.9
2016	5.6
2017	5.8
2018	16
2019	25
Average over 5 years	13

Source: (Markets Insider, 2020)