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Coal-Exit and Beyond: Structural Change and a Just Transition in Korea and Germany

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Content

Executive Summary

Energy Sectors in Germany and Korea

Germany and the Republic of Korea (hereafter Korea) have traditionally relied on fossil fuels, particularly coal, to fuel their industrialization and economic growth. Today, both countries are committed to decarbonizing their economy by 2045 and 2050 respectively. Germany initiated its transition towards renewable energy approximately two decades ahead of Korea. As of 2023, 52% of Germany's electricity is generated from renewables, while in Korea only around 9% is produced from renewable energy sources (Our World in Data et al. 2023c; Our World in Data et al. 2023b). Nevertheless, both countries still are substantial users of fossil fuels, the majority of which are covered by imports.

While Korea has only limited coal production capacities and thus relies on coal imports, Germany has historically produced a significant share of the consumed hard coal and lignite domestically. However, factors such as the unprofitability of lignite and hard coal mining in Germany have led to a sharp decline in the German energy sector over the past decades. Since 1991, direct employment has more than halved, primarily due to significant job losses in the coal industry, demonstrating the ongoing structural change in Germany. In contrast, the substantial workforce employed in the coal-fired power plant sector in Korea has not decreased to this day.

Policy Framework for Coal Exit

In order to trigger structural change in the energy sector, governments are compelled to implement policies that lead industries to enact the necessary changes. Korea and Germany choose similar policies and technologies with regard to decarbonization, such as increasing the share of renewables, the development of (green) hydrogen and the introduction of a carbon price. Moreover, both economies have fixed phase-out dates for coal energy: Germany set an exit date for 2038 at the latest, Korea plans to exit coal by 2050. 2050 is also the target date for climate neutrality in Korea. Germany has set a slightly more ambitious target of climate neutrality by 2045.

Despite its historically much larger and more influential domestic coal industry, Germany has long since begun the phase-out of coal and has anchored its exit strategy in a national law in 2020 (*Kohleausstiegsgesetz)*. Today, despite small setbacks due to the global energy crisis, Germany is on track to close its last coal mine, and stop operation of coal-fired power plants by 2038, and ideally already by 2030. Additionally, Germany implemented a legally binding emission reduction target, which will be checked on an annual basis as part of the Climate Protection law (*Klimaschutzgesetz)*. Korea's climate neutrality target is enshrined in law through the Framework Act on Carbon Neutrality and Green Growth (*Carbon Neutrality Act*). Since October 2022, concrete emission reduction targets are to be integrated into national budget planning (Climate Action Tracker 2023; MOTIE 2023). The exit date for coal-fired power generation, however, has not yet been put in legislation and is only mentioned in the 2050 Carbon Neutrality Scenario (Lee 2024a).

Drivers, Challenges and Opportunities

Despite their different trajectories of coal phase-out, both countries' development of structural change can be analyzed by means of its driving factors, its country-specific challenges and the opportunities and benefits which can be derived from a successful transition of the energy sector. In Korea, driving factors include: the concerning level of air pollution partly caused by coal plants; the push for a national coal exit by the governments of the biggest coal regions; and phase-out claims of large institutions like the Korean National Pension Fund. Prominent challenges that hinder a swift fossil fuel exit are of socio-economic; political; and societal nature and include lack of public acceptance of renewable energies; failed inclusion of stakeholders in civil society as well as the centralized political system, paired with a single-term presidency. At the same time, job creation, decreased pollution, energy independence, and even a halt to rising electricity prices are factors that will benefit the Korean public if structural change away from coal and towards renewable energies is implemented.

In Germany, the transition was driven by economic considerations due to the liberalization of European coal prices in 1958 and the German reunification in 1990 as well as in recent years the pressure from the international community and a civil society movement for climate action. The coal phase-out and structural change in the affected regions after 1958 and 1990 resulted in social, political and economic challenges such as the need for large-scale reemployment of coal workers and the disruption of the regional economy. Nevertheless, the ongoing transition reduces emissions, encourages the development of the renewable energy sector, and enhances the attractiveness of former coal regions.

Lessons-Learned and Recommendations

Considering the plans and experiences of both countries, it becomes clear that a just and timely transition away from coal requires a combination of policy measures: forward-looking policies such as attracting new industries, and reactive interventions, for example, retraining and early retirement programs for workers. Moreover, structural policy interventions should span various sectors and government levels to address not only economic but also social, ecological, and cultural aspects. To ensure a future-oriented development of coal regions, the diversification of economic

activities is crucial to enhance economic resilience, reduce the risk of structural breaks, and avoid lock-in effects.

By applying these lessons and recommendations, Germany and Korea can work together effectively to phase-out coal and other fossil fuels and ensure a just transition in the energy sector. Insights and lessons from Germany's history of coal phase-out could be applied to the Korean case as well as to a future phase-out of other fossil fuels, such as (natural) gas, in both countries. Furthermore, ensuring the acceptance of the phase-out of fossil fuels as well as for its renewable substitutes, is of great importance for the overall success of such undertakings. Thus, cooperation on the topic of communication and education regarding climate change and the energy transition can be very valuable to increase acceptance.

1 Introduction

In 2015, 196 parties at the UN Climate Change Conference (COP21) committed in the Paris Agreement to hold "the increase in the global average temperature to well below 2°C above pre-industrial levels" and if possible even below 1.5°C (UNFCC 2023). To halt climate change and global warming, countries around the world have to drastically reduce energy demand, increase energy efficiency and transform the energy system towards renewable and climate-neutral energy sources. While the energy transition mitigates climate change and provides benefits for the human health and the environment, it also poses challenges for the implicated sectors and markets. Especially for countries with a longstanding tradition of fossil fuel deployment in the energy sector, such as Korea and Germany, the required structural change of the energy sector has widespread impacts on technologies, resource availability, labor markets, and the political landscape.

In the context of this study, structural change refers to a deep shift in an economy from fossil fuels to climate-neutral sources of energy. It can be brought about by political, social, or economic developments. Successful structural change thus requires a dramatic shift in how capital is spent, how the labor force is trained and how resources are used. Moreover, it may result in new laws, changes in supply and demand, and the need for collaboration and knowledge sharing (Matthes 2017).

Structural change in the energy sector has historically been driven by the development of new technologies or the exploitation of newfound resources. Whether we look back at the shift from wood and charcoal to coal and later from coal to hydrocarbons, or the increasing use of electricity instead of primary energy (Smil 2004). What differentiates this current development from historical cases of structural change in the energy sector is the urgent need for climate change mitigation and thus, for a much faster pace of transformation compared to historic energy transitions, which tended to take place over many decades or even centuries (Kern and Rogge 2016).

Both Germany and Korea's energy sectors have a longstanding tradition of fossil fuel deployment, particularly coal. Despite on very different timelines, both economies have developed their status as industrialized nations, and gained wealth and international significance as a result of fossil fuel usage. Today, although again on deviating timelines, both countries seek to decarbonize their energy sectors and commit to phasing out coal by 2038 and 2050 respectively.

In Germany, the decline of the coal sector started in the 1960s and is characterized by three phases: the decline of hard coal mining in Western Germany from the 1960s, the restructuring of Eastern Germany's energy sector after reunification and the planned phase-out of coal power generation and lignite mining by 2030 or at the latest by 2038. The diminishing importance of the German coal sector can be illustrated by the development of employees in the coal industry. This number has fallen from a peak of around 156,000 people in 1989 to only around 17,000 employees today (Statista 2024). Because of the major changes in the sector in the past decades and the looming phase-out date for a large part of the industry by 2030, Germany's coal phase-out can be understood as nearly completed (Honnen et al. 2023). Therefore, Germany's decades-long experience with a declining coal sector and related policy responses provide many valuable lessons for other countries facing similar shifts in their energy sector.

Compared to Germany, Korea has a significantly larger coal sector today. While most of the used coal is imported from abroad, the sector provides around 50,000 jobs in generation, operation as well as maintenance, fuel management and pollution control of power plants and maintenance of coal plants (IEA and KEEI 2023). Therefore, to reach the country's goal of phasing-out coal by 2050, comprehensive policy measures are needed.

Through their Energy Partnership, Korea and Germany jointly work towards the common goals of decarbonizing the energy sector and accelerating the energy transition in both countries. Comparing the experiences of the German coal sector with Korea's current situation provides valuable lessons for how to shape a just transition and showcases how bilateral cooperation can support each country's climate goals. With this study, the trajectory and current state of each country's coal transition are outlined, scrutinizing its drivers, challenges and benefits. The ultimate aim of this study is to compare both Germany's and Korea's previous and ongoing efforts and to draw up lessons learned to support the coal exit in Korea through bilateral cooperation measures between both countries.

This study is organized as follows: Chapter 2 offers a brief overview of the energy sectors in Germany and Korea, along with key data on their energy mix. Chapter 3: examines the existing policies in both countries that aim to shift from fossil fuels to renewable energies. In Chapter 4, the current status of coal phase-out initiatives is explored in both nations, analyzing challenges and recommendations for bilateral cooperation are developed.

2 Energy sectors in Germany & Korea

This chapter provides a brief overview of the energy sectors in both Germany and Korea, including the share of coal use and the role of other energy sources in the energy mix.

2.1. Germany

Germany's economy is traditionally heavily reliant on fossil fuels for domestic energy production, a fact that remains unchanged despite its comprehensive expansion of renewable energies in the past two decades. In 2022, 31.1% of gross electricity was generated using lignite and hard coal, which are the most polluting energy sources. Natural gas contributed 16.5%, oil 3.2 and nuclear energy 6.3% of gross electricity production. Meanwhile, the combined share of renewables stood at roughly 42.9% with wind being the most prominent of Germany's renewable energy sources (Our World in Data et al. 2023c). Figure 1 describes Germany's primary energy consumption, comparing the years 1990 and 2022, and depicts key facts about the German energy economy. It shows, 35% and 22.9% of total primary energy consumption was generated by oil and natural gas in 2022, respectively. Lignite and hard coal contributed the third largest amount of 19.1% followed by renewable energies (20.4%) and nuclear energy (2.7%) (Our World in Data et al. 2023a). This shows the persisting reliance on fossil fuels for energy and electricity production.

Germany is the fourth-largest economy in the world, with a strong industrial sector and relatively few domestic natural resources. The country is thus a large importer of energy carriers: in 2020, Germany imported 70% of fossil fuels. In terms of energy sources, Germany's net import share was 100% for uranium, 98% for oil, 93% for hard coal, 88% for natural gas, and -2% for lignite, meaning Germany was a net exporter of domestically sourced lignite (BMWK 2022b). Germany is a noticeable producer of renewable energy, which represented the second-largest domestically produced energy source, after lignite, in 2021 (AG Energiebilanzen e.V. 2022a). Overall, Germany was a net electricity exporter every year between 2002 and 2022. In 2023 Germany imported more electricity than was exported for the first time in 10 years (Bundesnetzagentur 2021).

Having emitted 1.82% of total global GHG emissions in 2021, Germany is the world's sixth-largest GHG emitter (Our World in Data et al. 2020). Emissions reached 762 Mt CO2-eq in 2021, a 39% decrease since 1990. Of these, 91% of emissions in 2021 were energy-related (UBA 2022). Since the Industrial Revolution, the lion's share of emissions has been generated by burning coal. In the last 70 years, the burning of oil and gas has increased, while coal usage has declined (Our World in Data et al. 2020). Still, lignite and hard coal are responsible for 33% of today's energy-related CO_2 emissions in Germany (BMWK 2022b).

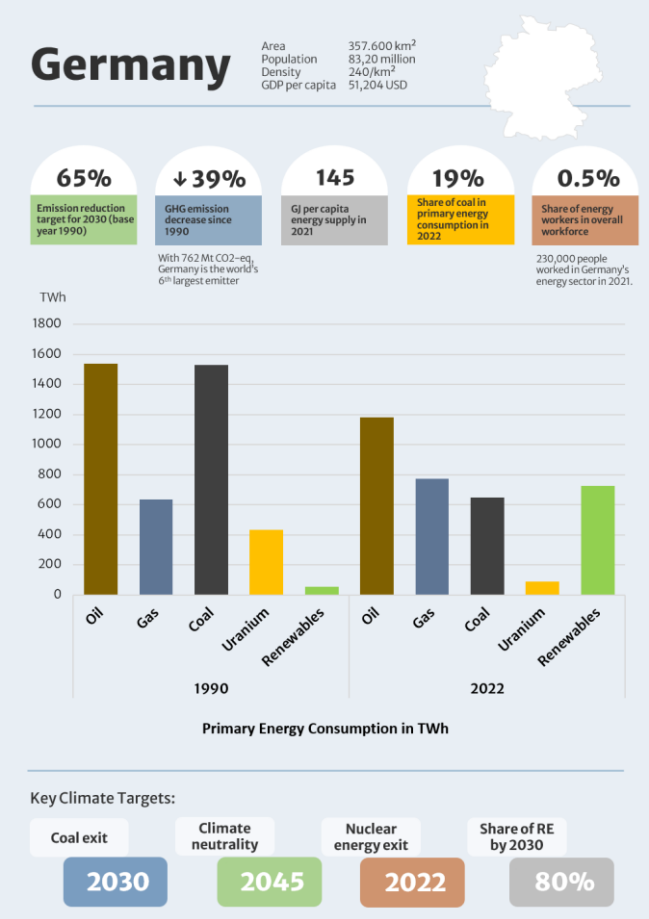

Figure 1: Germany - Energy facts and energy balance. Own depiction. This figure was first published in Honnen et al. (2023) and adapted for the purpose of this study. Sources:(BP 2022; Our World in Data et al. 2023a; Our World in Data et al. 2020; UBA 2022; BMWK 2022a)

While Germany is increasing overall domestic energy production through the deployment of renewables, it will likely continue to import energy carriers in the future, mostly climate-neutral carriers such as renewable hydrogen and its derivatives (Piria et al. 2022). Germany is still among the world's largest producers of lignite, even though production has been declining in recent years. While existing lignite reserves are enough to last for a long time, coal-fired electricity production and coal mining will have to be phased out in 2038 at the latest according to Germany's coal exit law (see next chapter for more details) (BMWK 2023). Estimates suggest that if Germany is to meet its climate targets, no new opencast mines are to be constructed, leaving

approximately half of Germany's total lignite reserves untouched (Agora Energiewende 2016).

In 2022, lignite still made up 10% of primary energy consumption (9.1% in 2021), being mainly used in electricity production (24.4 % of power generation in 2021) and district heating (AG Energiebilanzen e.V. 2022b, 2022a). Germany used to be a large producer of hard coal, but domestic production could not compete with cheaper imports and thus declined over the past decades. With the phase-out of subsidies for hard coal mining, production stopped completely at the end of 2018 (see Chapter 4). All of today's hard coal is imported, still representing 9.8% of primary energy consumption in 2022 (8.9 % in 2021) and 10.8 % of power generation in 2021 (AG Energiebilanzen e.V. 2022a, 2022b).

Direct employment in Germany's energy sector has seen a decline in the past decades from around 560,000 workers in 1991 to 220,000 in 2021 (BMWK 2022b). This decline is primarily due to the large decrease in employment in the coal industry, as well as employment regression in the power sector and to a lesser degree in oil refining (Deutsches Biomasseforschungszentrum 2023). At its peak in 1957, around 600.000 workers were employed at hard coal mines and plants. From there onwards, hard coal mining was phased out successively until 2018 when the last mine closed. Until today, there are still a few thousand workers employed in hard coal power generation but with plants closing continuously, this number is steadily declining (Statistik der Kohlewirtschaft e.V. 2022; Tagesschau 2020).[1] At its respective peak in 1989, the lignite industry counted around 156.000 employees in lignite mining alone.[2] In 2022, 17.000 workers were employed in coal mining and coal-fired power generation combined (Statistik der Kohlewirtschaft e.V. 2022).

As a traditional industrial economy, Germany's economic development has been tied to coal mining and coal burning. While Germany's dependence on coal has decreased over the last decades, the great influence of the coal industry is far from over. The steady decline of workers in the industry shows that structural change has occurred within the economy but the replacement of domestic coal with cheaper imported resources has led to continued burning of the fossil with over a third of total annual emissions still originating from hard coal and lignite combined. To understand Germany's history with coal and its more recent efforts of a just transition away from coal and other fossil fuels, Chapter 3 will take a look at the country's policies.

2.2. Korea

As of 2022, the shares of electricity generation in Korea are as follows: 34% from coal, 28.1% from LNG-fired power plants, 27.8% from nuclear, 1% from oil, and 9.2% from renewables (Our World in Data et al. 2023b). A slow uptake of renewable energy means that fossil fuels still dominate the energy mix, with renewables making up the lowest share of the energy mix among OECD member countries (Tachev 2021; IEA and KEEI 2023). In 2022, oil made up the largest share of Korea's primary energy consumption with 43.1%, followed by coal (22.7%), and gas (17.6%). Nuclear power contributed 12.5% and renewable energy sources 4.1%, respectively (Our World in Data et al. 2023a). The development of Korea's primary energy consumption is depicted in Figure 2, comparing the shares from 1990 and 2022. Further, it shows key facts about the Korean energy economy and political targets.

Historically, Korea has had minimal domestic coal production from its anthracite reserves. Over the past two decades, domestic mining has covered only a fraction of annual consumption, which in turn has grown steadily between 1992 and 2019 (EIA 2023). By now, Korea is the world's fourth-largest importer of coal. While it domestically produces around 1.2 Mt of coal per year, Korea imports over 150 Mt annually. Most of the foreign coal in Korea is imported from Australia, Indonesia, Russia, and Canada. Overall, Korea today relies on imports to meet almost 98% of its fossil fuel consumption (Bang 2021; EIA 2023).

Korea's total employment in fossil fuel-based energy and related commodities lies at 141,462 as of 2018. This corresponds to 0.6% of total national employment, which was 24.5 million in 2018. This number includes a range of different occupations including mining and manufacturing but also the operation of oil and gas stations as well as distribution and pipeline transportation (Pollin et al. 2022).

In 2021, Korea was the 13th largest economy and the 9th largest GHG emitter in the world, having emitted 1.66% of total global carbon dioxide emissions (European Commission 2022; Gallup Korea 2019; Statista 2023b). In 2022, the total volume of greenhouse gas emitted in Korea amounted to 646,06 million metric tons of carbon dioxide equivalent (Jones et al. 2024). CO2 emissions from coal-fired power generation made up 47.5% of the total emissions (IEA 2022).

Over the past 30 years, gas and coal have had a stronghold over the Korean energy market. Coal has created jobs, and provided a cheap and consistent power supply. It greatly contributed to Korea's industry being internationally competitive, and the expansion of coal-fired power plants has continued well into the 2010s (Jeong et al. 2021). While a coal exit date is in place and the government is working towards it, other measures for supporting the necessary

[1] Exact numbers for employment in the hard coal power generation sector are hard to obtain. Estimates from 2018 point to roughly 13.000 employees, 4000 of which were employed in the last remaining mines. Since their closure in the same year, it can be assumed that the remaining number of employees lies below 9000, tendency to decline.

[2] Again, numbers for employees in lignite-fired power generation were ambiguous before 2002, when plant workers and miners were equally registered.

structural change remain scarce. The next chapter will give an overview on the status of strategies and policies for structural change in Korea.

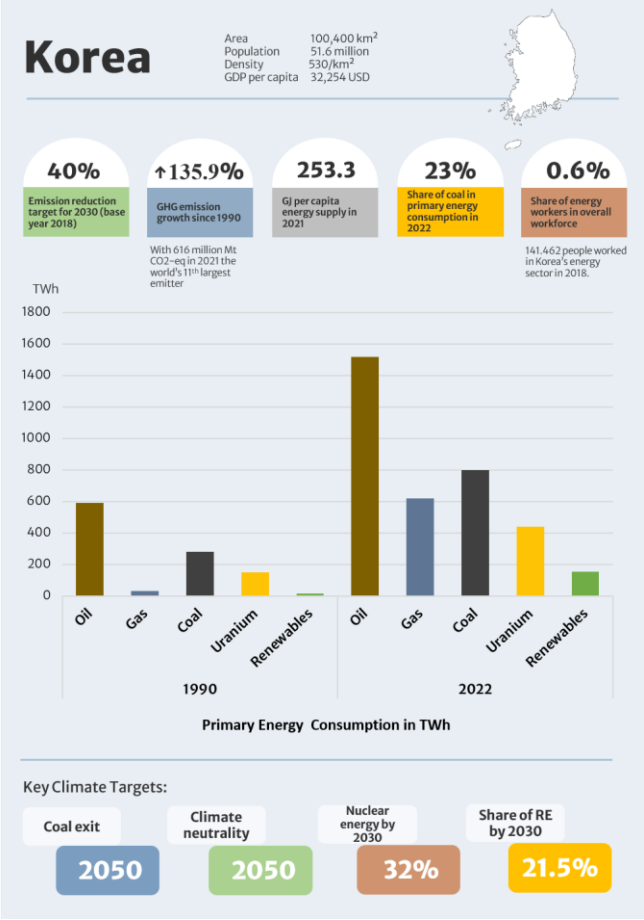

Figure 2: Korea - Energy facts and energy balance. Own depiction. Sources: (Our World in Data et al. 2023a; Our World in Data et al. 2023c; Kim 2023a; Robert Pollin, Jeannette Wicks-Lim, Shouvik Chakraborty 2022; Climate Change Performance Index 2022; World Nuclear Association 2023)

3 Policy Framework for Coal-Exit

Structural change in the energy sector has historically been driven by the development of new technologies or the discovery of new resources. These economically advantageous options would then dominate the market. However, what sets the current developments apart from previous instances of structural change in the energy sector is the pressing need for climate change mitigation. Effective change now relies heavily on robust policies, which often conflict with a country's short-term economic interests. This section outlines the existing policies in both countries that aim to shift from a fossil fuel-based (primarily coal and gas) industry to renewable energy sources.

3.1. Germany

3.1.1. Climate Targets

As part of the European Union, Germany is required to comply with the EU's Nationally Determined Contribution (NDC) to the Paris Agreement: a net domestic reduction of at least 55% in greenhouse gas emissions by 2030 compared to 1990. Moreover, Germany has set the preliminary targets of cutting emissions by at least 65% by 2030 compared to 1990 levels, and 88% by 2040 and aims to become GHG neutral by 2045. These targets are established in Germany's Climate Protection Law (*Klimaschutzgesetz).* To achieve these climate targets, emissions must be reduced in all sectors of the economy, most notably the energy sector.

3.1.2. Coal Exit Strategies

In 2018, the government established a task force referred to as the "coal commission" to successfully phase-out coal, while preserving economic stability, and providing social security to the industry's workforce. This commission included representatives from trade unions, industry, NGOs, municipalities, and expert organisations (Gürtler et al. 2021). It suggested a phase-out plan until 2038, €40 billion in funding for coal regions, compensation payments for industry, and social policy measures such as early retirement. Largely following the Commission's recommendations, the federal government proposed a legislative package that was adopted by Parliament in July 2020: the coal phase-out law (*Kohleausstiegsgesetz*)[3] and the structural support law for coal regions (*Strukturstärkungsgesetz Kohleregionen*)[4]. The federal Parliament elections in September 2021 resulted in a new government coalition led by the *SPD* (social democrat party) with *Bündnis 90/ Die Grünen* (green party) and the *FDP* (liberal party). The new government has since expressed plans to move the coal phase-out date forward to 2030. However, the energy crisis caused by Russia's aggression war against Ukraine sparked a renewed debate about a runtime extension for coal power plants to ensure power and heat supply. To compensate for gas shortages, a number of hard coal power plants were temporarily retrieved from the grid reserve. In September 2022, the federal government decided that these power plants would be allowed to operate until March 2024, a year longer than originally planned. From April 2024 onwards, these plants were officially taken off the grid (ZDF 2024). In April 2024, the G7 energy and climate ministers agreed to "phase out existing unabated coal power generation in our energy systems during the first half of 2030s or in a timeline consistent with keeping a limit of 1.5°C temperature rise within reach, in line with countries' net zero pathways." This agreement is considered a significant stride in the global phase-out of fossil fuels (Wettengel 2024).

3.1.3. Further National Policies

The German government aims at significantly expanding the share of renewable energy in the next years. In light of the increased climate neutrality target until 2045, an amendment to the long-established Renewable Energy Act *(Erneuerbare Energien Gesetz)* has been passed in 2022. By 2030 renewables shall make up 80% of Germany's electricity demand. To achieve this target, the expansion paths for solar and onshore wind have been raised significantly. For solar energy, expansion rates are increased to 22 gigawatts (GW) per year with tender volumes divided equally between rooftops and open spaces. In 2030, photovoltaic (PV) systems totaling around 215 GW are to be installed. For

[3] The coal phase-out law encompasses the following main components: a law to reduce and ultimately cease power generation with lignite and hard coal; an amendment to the energy industry act (*Energiewirtschaftsgesetz)* granting subsidies to the transmission network charge and transferring the task of monitoring the security of energy supply to the federal network agency *(Bundesnetzagentur); an amendment to the Renewable Energy Act (EEG),* targeting 65% renewable energy in the electricity mix, an amendment to the Combined Heat-Power Act (CHP) (*Kraft-Wärme-Kopplungsgesetz)* including the extension until 2030 and regulations for the further development of CHP and consequential amendments: Amendment to the Combined Heat and Power Act Fee Ordinance and the CHP Tendering Ordinance and finally an amendment to the Emissions-Trading Law (*Gesetzes über den Handel mit Berechtigungen zur Emission von Treibhausgasen*) namely the cancellation of CO2 allowances released from the EU ETS.

[4] The structural support law for coal regions is applied in combination with the investment law for coal regions and lays out how the assigned budget will be spent to assure successful measures for structural support of the affected regions. The investment law for coal regions provides for €40 billion in funding for coal regions, planning €14 million for regional and municipal measures and €26 million for federal measures. As part of the law, the Federal Ministry for Economic Afairs and Climate Change (BMWK) is required to monitor the progress of this law with a biennial report.

onshore wind energy, the capacity is to be increased by up to 10 GW per year to reach an installed capacity of around 115 GW for onshore wind turbines in Germany by 2030 (*Wind-an-Land-Gesetz*) (Staudenmaier 2023). The target volumes for installed offshore wind energy were increased by the 2023 amendment to the Wind Energy At Sea Act (*Wind-auf-See Gesetz*) to at least 30 GW by 2030, at least 40 GW by 2035, and from 40 GW to at least 70 GW by 2040 (Bundesregierung 2023a; BMWK 2022a).

In sectors where decarbonization through direct electrification will be challenging or costly such as heavy industry, shipping or aviation, green hydrogen and its derivates are a key element of the German energy transition. The national hydrogen strategy aims at fostering the creation of a strong domestic hydrogen market to make hydrogen a competitive low-carbon fuel. 10 GW of electrolysis capacity are to be installed in Germany by 2030. However, the future demand for hydrogen of approximately 90-110 TWh by 2030 will exceed domestic supply. Since renewable generation capacities within Germany are limited, Germany intends to meet its demand through imports (BMWK 2023a).

In order to reduce carbon dioxide emissions, the European Union introduced the European Emission Trading System (EU ETS) in 2005. This system limits emissions from around 10,000 installations in the energy sector, manufacturing industry and air transportation in the 27 EU countries plus Iceland, Liechtenstein and Norway. The downstream cap-and-trade system covers around 40% of the EU's greenhouse gas emissions (European Commission 2023). In September 2023, the cost per tonne of carbon dioxide produced was around 85€ (Ember 2023).

However, the EU ETS covers only a portion of the CO2 emissions produced in Germany. To ensure that companies decarbonize and the demand for fossil fuels is driven down in the industry and on the consumption side, Germany has established an Upstream National Emissions Trading Scheme, where the industry passes on the price of emissions certificates to consumers. Under this scheme, entities responsible for emissions, such as gas and coal suppliers, are required to pay for the emissions from the eventual use of their products by end-users. These additional costs are subsequently passed on to the consumers. The motivation behind this is its applicability to sectors like heating and transportation, which feature a multitude of emitters. Rather than all these individual emitters participating directly in the national emission trading system, participation occurs through the companies. This scheme currently entails a CO2 price of €30 per ton of emitted CO2. This price is set to gradually increase, reaching a target range of €55-65 per ton of emitted CO2 by the year 2026 (UBA and Deutsche Emissionshandelsstelle 2023). There is the general assumption that, under this scheme, coal-fired power generation will become unprofitable before the official phase-out date in 2038, making an earlier coal exit possible (Schrems 2021).

In addition to decarbonizing the energy sector, another target of the German energy transition was to phase-out nuclear energy, which was accomplished in 2023. Nuclear generation continuously increased between the 1970s and 1990s, plateaued afterward and decreased from 30% of electricity generation in 2005 (IEA 2020) to 0% after the shutdown of the three last remaining operational nuclear plants in April 2023.

3.2. Korea

3.2.1. Climate Targets

In June 2020, 226 out of 228 Korean local governments declared a state of climate emergency and requested government and National Assembly to work towards achieving climate neutrality by 2050. In 2020, the National Assembly passed a climate emergency resolution and established the comprehensive yet non-binding *Carbon-Neutral Strategy,* which includes the goal of reaching net zero emissions by 2050 (European Parliament 2021). In 2021, the country passed its *Framework Act on Carbon Neutrality to Respond to Climate Crisis* (the Carbon Neutrality Act), stipulating that the Korean NDC should be at least 35% emission reduction by 2030 compared to 2018 (Climate Change Laws of the World 2023). After international critique regarding the country's rather unambitious NDC, President Moon (in office from 2017 to 2022) strengthened the target to a 40% emissions reduction by 2030 compared to 2018 levels (Kim 2023b). This demonstrated a significant improvement in contrast to the previous NDC of 24.4% reduction compared to 2017 levels (Government of the Republic of Korea 2021). Since October 2022, concrete emission reduction targets must be integrated into national budget planning (Climate Action Tracker 2023; MOTIE 2023).

3.2.2. Coal Exit Strategies

The previous government under President Moon put significant emphasis on the reduction of coal production and its replacement with renewable energies. As such, the government banned the construction of new coal-fired power plants except for those already under construction (IEA and KEEI 2023). While the above-mentioned *Carbon Neutrality Act* stipulates the target of net zero by 2050 and therefore encompasses a necessary phase-out of unabated fossil fuel use, a concrete coal-exit target has never been enshrined in law (Jang 2024). However, the goal was made explicit by the Moon government at the COP26 in 2021.

While in office, the Moon government completed a final shutdown of ten coal plants. The further conversion of 28 additional plants from coal to LNG was consolidated in the *10th Basic Plan for Electricity Supply and Demand* (hereafter referred to as '10th Basic Plan') under the current Yoon administration, which was officially released in March 2023.

The *10th Basic Plan* also entails plans to reduce GHG emissions by using carbon-free sources, such as ammonia or hydrogen, to reduce emissions from coal plants until their final phase-out. For ammonia, the plan is to realize co-firing projects with 20% content until 2027; commercialization of 20% co-firing until 2030; and 100% ammonia-fuelled firing by 2050 (IEA and KEEI 2023).

In 2019, the Ministry for Economy and Finance (MOEF) increased the coal consumption tax by 28% while reducing the consumption tax for natural gas by 75% (IEA 2022). Along the same line of action, the government reduced the LNG import taxes by 85%. All of these measures combined have increased the competitiveness of natural gas with coal for power generation (EIA 2023).

3.2.3. Further National Policies

The aforementioned *2050 Carbon-Neutral Strategy* puts forward a detailed plan on how to achieve the Korean carbon neutrality target. The strategy contains five key elements: 1.The expansion of clean power and use of hydrogen in all sectors; 2. A significant improvement in energy efficiency; 3. The deployment of Carbon Capture and Storage (CCUS); 4. The use of circular economy principles to improve sustainability in industry and 5. The enhancement of carbon sinks (Government of the Republic of Korea 2020).

For the promotion of renewable energy, the Korean government has implemented the *Renewable Portfolio Standard* (RPS) which requires major electric utilities to increase their renewable energy share in the electricity mix to 10% by 2023 (Korea New and Renewable Energy Center, 2019), and to 25% by 2034 (Climate Action Tracker 2023). According to Our World in Data, Korea's electricity mix contained 8,66% renewable energy in 2022 (Our World in Data et al. 2023b).

The Yoon government, with the release of the aforementioned *10th Basic Plan* in March 2023 set a target share for renewable energy in the electricity mix of 21.6% until 2030 (Climate Change Performance Index 2022). Rather than solely focusing its efforts on renewable energy sources, the Yoon government places high strategic priority on nuclear energy, framing it as one of the country's main solutions for low-carbon energy (Kim 2023c). It has thus scraped the previous decision of phasing out nuclear energy over the long run and has set the target of providing at least 30% of electricity with nuclear energy by 2030 (World Nuclear Association 2023).

To support economic growth and industrial competitiveness while reducing GHG emissions in the long run, Korea adopted its *Hydrogen Economy Roadmap* in 2019, detailing a plan to establish hydrogen as a cornerstone in the country's energy mix. It foresees a growth in Korea's hydrogen development leading to energy consumption replaced by hydrogen of about 10.4 million tons of oil equivalent in 2040 – equal to 5% of total expected energy consumption or total liquid natural gas (LNG) consumption by domestic households in 2016 (MOTIE 2024). In 2021, Korea had the third-largest public investment in hydrogen after Germany and Japan (Jane Nakano 2021).

South Korea's Emissions Trading Scheme (K-ETS) was launched in 2015 as East Asia's first nationwide mandatory ETS and, at the time, the second-largest carbon market after the EU ETS. It includes the following sectors: industrial, power, buildings, waste, and domestic aviation. In 2022, the government conducted regular meetings with relevant ministries, enterprises, associations, and experts as part of an extensive stakeholder consultation process for a revision of the mechanism ahead of its next phase. This has resulted in an array of proposals, with 33 already approved for near-term implementation through revisions to existing guidelines. The remaining proposals focus on longer-term reforms, which are still under review and are expected to be introduced with the new rules for Phase 4 of the K-ETS, starting in 2026 (ICAP 2022). These address some of the general points of criticism against the K-ETS, such as an over-allocation of pollution permits, resulting in financial gains for polluters and generally weak governance of the scheme, resulting in low efficiency and ineffective monitoring and evaluation procedures (ICAP 2022; Time; Lee 2024b). As is the case in Germany, the K-ETS holds a great potential to contribute to an early phase-down of coal-fired power plants if above-mentioned issues are resolved.

4 Status Quo, Challenges and Opportunities

This chapter gives an overview of the current status of coal phase-out in both countries and subsequently contrasts driving factors as well as challenges and opportunities of a swift and complete coal exit.

4.1. Germany

Please note that the following section (4.1.1) was first published in "Supporting the just transitions in Canada and Germany. Lessons from sixty years of coal phase-out in Germany" by Honnen et al. (2023) and has been moderately edited for the purpose of this study.

4.1.1. Status Quo

Germany has a long history of structural change in the coal industry, which can be separated in three processes: the decline of hard coal mining in Western Germany from the 1960s, the restructuring of Eastern Germany's energy sector after reunification, and the ongoing nationwide phase-out of coal power generation and lignite mining by 2038 at the latest.

Decline of hard coal mining in Western Germany since the 1960s

Hard coal was the cornerstone of West Germany's post-war economic, social, and political reconstruction. The number of people directly employed in the industry peaked at around 600,000 in 1957 (Oei et al. 2020a).

However, in 1958 European coal prices were liberalized leading to a price drop that made coal from overseas and imported oil cheaper in comparison to domestic coal. As a result, Germany's hard coal production and employment entered a rapid decline. Through subsidies, however, the phase-out was drawn out over a long period of time as an attempt to ease the transition and cushion social hardships. Subsidies for hard coal amounted to €289 - €331 billion from 1950 to 2018. It was only in 2007 that the growing influence of the EU forced Germany to implement a law which ended subsidising of hard coal mining by 2018 (Meyer et al. 2010).

Moreover, the decline of the hard coal mining industry in West Germany was addressed by German politics with structural policies. These were aimed at solving (local) economic, social and, to a lesser extent, environmental problems.[5] Climate considerations did not yet play a role, hence, despite the mine closures, most coal-fired power plants kept operating and switched from domestic to cheaper imported hard coal (Honnen et al. 2023).

For instance, in the Ruhr area, which was considered the 'industrial heart' of Germany due to its coal and steel industry (Petzina 1984 quoted by Dahlbeck et al. 2022, p.72), the first structural policies aimed to halt the decline of the coal industry and to reduce the negative effects on workers, e.g., by subsidising hard coal and offering retraining and early retirement opportunities. However, attracting new companies to increase economic diversification proved difficult, and was met with resistance from mining companies, politicians, and unions. Moreover, subsidies and policy measures were distributed unequally between the northern and southern parts of the region due to lagged closure of mines. This led to lower economic power and higher levels of (long-term) unemployment in the Ruhr area compared to the rest of Germany (Dahlbeck et al. 2022; Oei et al. 2020a).

Beginning in the 1980s, structural policy programs became more inclusive and regionalised, including the establishment of 'lead markets' and more polycentric coordination. Ecological and cultural aspects received increasing attention as well (Oei et al. 2020a). With the turn of the millennium a more sector expertise-oriented structural policy was implemented in the Ruhr Area (Bogumil et al. 2012). These changes in policy allowed for increased entrepreneurial activity and diversification of the region. Results from the holistic and adaptive support program approach, which is still applied to this day, can be seen for instance in the developments of the Ruhr Area in the 2010s. This period was marked by a growing independence of the cities in the Ruhr area, each creating their individual development strategies (Oei et al. 2020a).

In contrast, the federal state Saarland, though comparatively less imprinted by its coal history, was dependent on a single industry (Oei et al. 2020a). Because coal mines were publicly owned, the state and federal government had more influence over the transition process and the so-called "ground lock" was not as much of an issue. Driven by the demand by car companies and their suppliers for a workforce with skills similar to those of former coal and steel workers, the Saarland mainly transitioned from coal and steel to the automotive industry (Oei et al. 2020a; Lerch 2007). However, the shift to the automotive industry resulted in a new dependency on a single, large sector for job and income creation. However, as a greenhouse-gas intensive industry

[5] Hard coal was mined solely in West Germany. East Germany relied on lignite due to a lack of hard coal mines.

itself, the automotive sector will have to substantially transform over the coming years (Niewel 2022).

An important paradigm during the phase-out of hard-coal mining was 'no miner shall be left behind'. This goal was indeed achieved as those who could not find alternative employment (e.g. in the metal industries) were offered retraining or early retirement schemes. However, this did not apply to up- and downstream industries, which were also significantly affected. Hence, structural policy also had to focus on diversification of the regional economy as well as the connectedness with neighbouring regions (Oei et al. 2020a).

All things considered, neither region has yet completed a just and in-time transition. Only domestic mining was phased out, while power plants shifted to the use of imported hard coal, which is not in accordance with the concepts of climate and intergenerational justice. There has not been a phase-out plan for hard coal power plants until as recently as 2020.

1990: Restructuring of Energy Sector in Eastern Germany

In the German Democratic Republic (GDR), domestic lignite was the most important energy source. It covered about two-thirds of primary energy demand in the 1975-90 period, enabling East Germany to establish heavy industry and gain some independence from Soviet oil and gas imports (Hermann et al. 2017). The GDR as the world's largest producer of lignite, had two major mining regions: Lusatia (*Lausitzer Revier*) and Central Germany (*Mitteldeutsches Revier*) with Lusatia being the larger of the two (Wolle 2020). Because hard coal deposits are only located in West Germany, there were no hard coal mines and power plants in East Germany (Furnaro et al. 2021). Today, there are few power plants utilizing hard coal in East Germany mostly located along delivery routes of hard coal imports or in areas with high energy demand (UBA 2021).

In 1990, the German reunification led to a sudden system change in the former GDR from a centrally planned economy to a market economy. A large-scale de-industrialisation ensued that affected many sectors, including large parts of the Lusatian lignite industry. Many East German industries were no longer able to keep up with the competition from the West, as they had lower levels of productivity, were based on outdated technology, or sold to external investors for short-term profits in the years after the reunification (Ragnitz et al. 2022; Walk and Stognief 2021).

The geological conditions in Lusatia made lignite mining and generation very expensive, which was one of the main reasons for the closure of large parts of the industry after 1990 (Ragnitz et al. 2022; Walk and Stognief 2021). The result was a sudden structural break that left tens of thousands of people without employment. In 1989, the Lusatian lignite industry had still provided 80,000 jobs, but in the early 2000s, the number of jobs had reduced to less than 10,000 and unemployment rates rose to over 20% (Hermann et al. 2017; Gürtler et al. 2020; Noack 2022). Nearly a fifth of the region's inhabitants left over the 1995-2015 period, many of them young and with high levels of education (Schwartzkopff and Schulz 2015).

The economic and social situation in the 'new federal states' (*Neue Bundesländer*) became a major policy issue following the reunification. However, most major interventions applied to all of East Germany and were not specifically tailored to the regional characteristics or identity of Lusatia or other coal regions. Initially, the main policy was the so-called *'Aufbau Ost'* ('development East'), which was mainly reactive and focused on labour market and social policy topics: early retirement schemes, retraining, and job creation programmes. While those measures helped cushion social hardships, overall demand for labour remained too low for the job creation schemes to achieve lasting positive effects. Another cornerstone of the *'Aufbau Ost'* policy was investment funding by means of subsidies that brought the real capital costs below market level. Investment loans, subsidies, and equity grants were successful in attracting private investment initially, but this development did not last and investment activity underwent a large decline once again, possibly because there were not enough profitable investment opportunities available (Ragnitz et al. 2022).

Starting in the late 1990s, structural policy became more forward-looking with the objective of supporting structural adaptation. The emphasis shifted towards solving the problems of skill shortages and out-migration by means of innovation funding and a stronger focus on technology. Whereas previous funding programmes had largely been open for investments in any sectors, there was now a stronger focus on research and development activities, cluster formation, as well as the economic viability and attractiveness of jobs (Ragnitz et al. 2022).

In the early 2010s, the discourse on lignite and the remaining jobs in the industry intensified as climate concerns and a demand for coal phase-out became more prominent (Ragnitz et al. 2022; Markard et al. 2021). In 2020, thirty years after the reunification, a nationwide coal phase-out law was adopted by the German government. Lusatia is now facing the second major structural change process within a relatively short period of time while it still suffers from the consequences of the poorly handled post-reunification years (Walk and Stognief 2021). Despite the shrinkage that has already materialized and despite multiple changes to its ownership structure that have occurred since the

Figure 3: Lignite production and employment, 1990 and 2020. Own depiction based on DIW Berlin et al. (2018) and Statistik der Kohlenwirtschaft e.V. (2022).

reunification, the Lusatian lignite industry is still the largest employer in the region and the identity as an 'energy region' is still quite strong. As employment had already decreased from around 65,500 in 1990 to less than 8,000 in 2020 (see Figure 3), the number of jobs that will have to be replaced is much smaller now than after reunification. Still, there are few alternatives that provide similarly stable, unionised, and well-paid jobs. At the same time, the region is facing major skill shortages and has only limited success attracting skilled workers from other regions. Moreover, it is less well prepared to handle the transformation due to its remote location, less favourable economic conditions, lower innovation capacity as well as demographic and cultural factors (Stognief et al. 2019).

Nation-wide phase-out of coal power generation and lignite mining by 2038

Since the closure of the last mine in December 2018, there is no more hard coal mining in Germany (although there are still active power plants that run on imported hard coal). Lignite mining, on the other hand, is still an active industry, as is power generation based on lignite.

As of 2019, there were still around 20,000 people directly employed in the lignite industry in Germany, though this number has declined significantly in the last thirty years, especially in the two Eastern coalfields (see Figure 3). Indirect and induced employment figures are significantly higher. In the affected regions, the lignite industry is still a major economic factor and a pillar of regional identity.

In recent years it has become more and more clear to both the public and to policymakers that phasing out coal must be one of Germany's main contributions to meeting its climate targets. Against this backdrop, the topic of structural change in Germany's coal regions has once again been put on the political agenda of the federal government as well as of affected states and local governments. Since the main driver of the transition is climate change mitigation rather than economic considerations, the debate is marked by a paradigm shift: Compared to, for example, the hard coal mining phase-out, there is now an awareness that the time frame for this transition will be much shorter than that for previous transitions. Moreover, there is a stronger emphasis on forward-looking, region-specific policies as well as stakeholder participation (Reitzenstein et al. 2022).

Before the early 2010s, the option of phasing out coal was barely considered in the political debate (Furnaro 2022). It was mainly the 2015 Paris Agreement that increased pressure on the coal industry, making a gradual reduction of coal use inevitable (Leipprand and Flachsland 2018). A highly controversial debate followed, involving diverse stakeholders with diametral interests. As discussed in Section 3.1.2., the *Commission on Growth, Structural Change and Employment* was set up (also referred to as 'Coal Commission') and provided recommendations for a German coal phase-out by 2038. For more information on the coal commission please see Figure 4 "The German Coal Commission: set-up and results".

In response, the federal government proposed a legislative package that was adopted by the German parliament in July 2020: the coal phase-out law (*Kohleausstiegsgesetz*)and the structural support law for coal regions (*Strukturstärkungsgesetz Kohleregionen*). Following the federal parliament elections in September 2021, the governing coalition partners agreed to accelerate the coal phase-out date preferably by 2030 (Bundesregierung 2023b).

4.1.2. Drivers

The German coal phase-out and related transition processes have mainly been driven by historical political developments and landscape pressure. The three main drivers are discussed in the following.

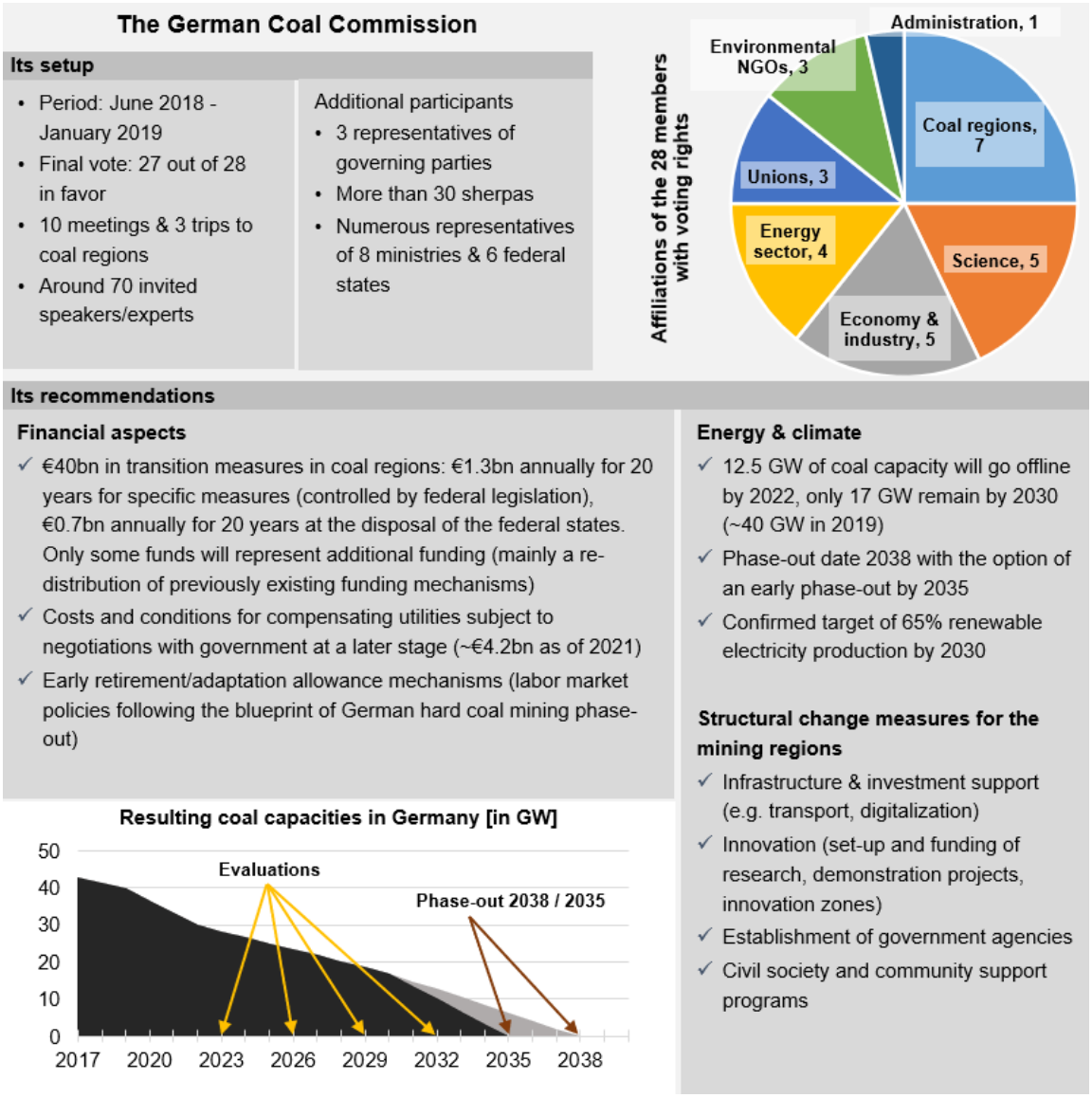

Figure 4: The German Coal Commission: Set-up and results. Source: Hauenstein et al. (forthcoming) based on Kommission Wachstum, Strukturwandel und Beschäftigung (2019). Reproduced with permission and first published in (Honnen et al. 2023).

First, the liberalisation of the European coal prices in 1958 and the resulting price drop made coal and oil imports cheaper than the German equivalents. This rendered the production of hard coal in Germany unprofitable. Although the price differences were initially offset by subsidies, compliance with EU legislation made a termination of these necessary by 2018 (Meyer et al. 2010). This resulted in the closure of all remaining hard coal mining facilities in the same year.

Second, the German reunification in 1990 and the related sudden system change in the former GDR from a centrally planned economy to a market economy affected the East German lignite sector heavily. The reduced economic profitability of the sector and overall structural disruptions made a transition and support policies at the federal and state level necessary.

Last, pressure from the international community and domestic civil society fostered the transition of the German energy sector. Germany traditionally has a strong environmental movement since the 1970s. However, until the 1990s the national movement was predominantly vocal about a nuclear phase-out. Concerns regarding the adverse consequences of coal mining and firing were mostly articulated by local initiatives. In the 1990s, the topic of climate change became more salient. Nevertheless, concerns were exclusively focused on the adverse economic effects on the coal industry. In the aftermath of the Fukushima meltdown in 2011, the '*Energiewende*' law was enacted with the aim of phasing out nuclear power as well as reducing GHG emissions, and increasing energy efficiency. However, many Germans felt uneasy with a simultaneous phase-out of both nuclear and fossil fuel energy (Renn and Marshall 2016). With both phase-outs contested in domestic society, the international community provided an additional impulse for

the discourse on the coal phase-out with the 2015 *Paris Agreement* (Leipprand and Flachsland 2018).

4.1.3. Challenges

The German coal phase-out and structural change presented itself with a wide array of challenges. Especially in the lignite regions, the lignite industry and related companies played a central role and provided the majority of jobs and economic opportunities in the region. Thus, the breakdown of these industries had major social, political and economic impacts and affected the attractiveness of the regions. In the following section, the main challenges are presented.

Political challenges

With the phase-out of hard coal mining and the restructuring of the energy sector in East Germany in the past, both the federal as well as state level governments faced difficulties in formulating an effective response to mitigate the adverse consequences of a transformation. Early policies in the Ruhr Area were mainly reactive and aimed at halting the coal industry's decline. These policies triggered resistance by workers and companies and proved to be ineffective (Brauers et al. 2018). Policies were not adapted to the region's individual challenges and potentials, nor did they account for the impact on neighboring regions in the structural support programs (Ragnitz et al. 2022). Moreover, benefits from structural policy measures were unevenly distributed within regions, e.g., north versus south Ruhr area, and across regions, i.e., West versus East Germany, perpetuating disparities (Brauers et al. 2018; Oei et al. 2020a; Dahlbeck et al. 2022). The effects of the untargeted policies are still widely evident today: not only in the Ruhr area but also in Lusatia where there are overall less favorable economic conditions, has reduced attractiveness for new business and experiences demographic decline which can be related to the choice of transition policy applied (Brauers et al. 2018; Ragnitz et al. 2022).

The Ruhr Area government's failure to communicate the phase-out of hard coal mining early on hindered economic diversification and increased transition costs (Dahlbeck et al. 2022). The lack of stakeholder involvement and the failure to consider their opinions led to strong resistance. For instance, the "ground lock" by private mining companies in response to governmental policies prevented faster measures and hindered the settlement of new companies (Brauers et al. 2018; Oei et al. 2020a; Dahlbeck et al. 2022).

Another significant challenge arises from the substantial costs associated with the transition. In the past, the affected regions and the coal industry received substantial compensation payments financed through taxes (Hauenstein et al. forthcoming). For instance, between 1950 and 2018, hard coal subsidies for companies in the Ruhr area alone amounted to €289-331 billion (Meyer et al. 2010). As of today, the majority of the direct costs associated with the coal phase-out, including subsidies, compensation payments, and relief funding, continue to be shouldered by national and federal state budgets (Brauers et al. 2018; BMWK 2023c). The coal commission has budgeted of €4.35 billion for support schemes within the phase-out of lignite and €0.73 billion for the phase-out of hard coal under the *Act on the Phase-out of Coal-fired Power Plants (*Kohleausstiegsgesetz). A further €40 billion are budgeted for regional investments to compensate for lost jobs and create new jobs in the lignite sector and an additional €1.9 billion in the hard coal sector under the structural support law for coal regions (*Strukturstärkungsgesetz Kohleregionen*) (BMWK 2024).

Economic challenges

The ongoing transition and planned phase-out of coal has been a challenge for those employed in the German coal sector, a fact that remains true today. Although many workers from the hard coal industry were able to secure new employment through retraining and reemployment efforts, the situation was far more complex for those directly involved in opencast mining, i.e. the extraction of raw materials, within the lignite industry. Being the largest group of workers in the lignite sector, the few matching job opportunities offered in the lignite regions were not enough to absorb this group (Oei et al. 2019). Consequently, facilitating their transition to alternative industries has been and still remains an intricate task that necessitates additional measures (Oei et al. 2020a).

Particularly because of this difficulty, structural policies implemented in the hard coal mining regions along with alternative employment schemes were primarily directed at finding alternative employment for miners. Unfortunately, these efforts overlooked workers in up- and downstream industries, leaving them vulnerable to these effects of the transformation (Oei et al. 2020a). Furthermore, the impact of the coal transition affects less women than men, yet these gender-specific distinctions were not considered in the policies (Walk et al. 2021; Braunger and Walk 2022).
Apart from these direct effects on the mining and coal industry as well as related downstream businesses, the transition introduced some additional challenges for the economy.

The West German regions experienced a general trend towards greater economic diversification and growth in the knowledge sector (Brauers et al. 2018). Nevertheless, new dependencies on often single and large carbon-intensive industries for income and job creation occurred. For instance, the automotive sector took over the position of the coal and steel industry in Saarland because suppliers needed a workforce with a skillset similar to that of coal and steel workers (Lerch 2007; Oei et al. 2020a). Nonetheless, this industry must also transform over the coming years in order to meet the German net zero emission goal by 2045, bringing further challenges (Niewel 2022).

In East Germany, the transition of the mining sector, precipitated by the collapse of the economic and political system, remains a major challenge for the region and its economy (Brauers et al. 2018). Despite the gradual decline, the lignite industry in Lusatia still accounted for about 4% of the region's gross value added in 2014 and employed approximately 8,000 people directly (DIW et al. 2018). Moreover, the region has a comparatively poorer

infrastructure, less favorable economic conditions and struggles to attract new businesses (DIW et al. 2018; Brauers et al. 2018).

According to a study by Stefan Gärtner (2019), innovation tends to occur more often in densely populated areas with good knowledge pathways, characteristics that are currently sparsely found in Lusatia (see 4.1.3). To this day, much of the investment support originates from outside the region, and many projects heavily rely on the financial and knowledge assistance provided. Consequently, when and if this support diminishes, numerous projects will struggle to sustain themselves (Brauers et al. 2018).

Challenges related to the energy supply and infrastructure

The coal phase-out poses a significant challenge for the current German energy and electricity supply. As highlighted in section 2.1., lignite and hard coal amounted to 17.5% of the 2021 total primary energy consumption and 29.4% of gross electricity production. To meet the 2045 net zero emission target and accomplish a coal phase-out, it is imperative to replace coal-fueled energy with renewable energy sources. Several studies (BCG and Prognos 2018; UBA 2017; Öko-Institut and Fraunhofer ISI 2015) have demonstrated that an expansion of renewable energy sources in Germany combined with enhanced energy efficiency could offset the losses resulting from the phase-out of both nuclear and fossil-based power generation by 2030 (DIW et al. 2018).

Replacing energy sources will require a fundamental transformation and restructuring of the energy system to ensure a stable energy supply. Because renewable energy sources provide varying amounts of electricity depending on external conditions, the supply will be more volatile in comparison to the more consistent base load provided by fossil fuels. Therefore, the electricity system and demand will have to become more flexible. For this, next to the general expansion of the electricity grid, additional infrastructure such as smart meters and storage options is needed (DIW et al. 2018).

It is assumed that the gradual shutdown of coal-fired power plants until 2030 could lead to an increase in the overall electricity exchange prices because of a changed merit order. For instance, if decommissioned lignite and hard coal-fired power plants are replaced with gas power plants, marginal costs may rise leading to price increases. However, these changes are also dependent on developments in the foreign electricity trade, the expansion of (domestic) renewable energy capacities, the carbon price, and (international) fossil fuel prices (DIW et al. 2018; Arnold et al. 2020). The Öko institute has modeled different scenarios considering the above-mentioned aspects. The authors show that the policy-induced shutdown of coal-fired power plants in Germany has a price effect of approximately 0.4 ct/kWh. However, increases in renewable energy supply have the potential to offset these developments. Overall, the authors conclude that electricity price effects of the German coal phase-out should be small for the German economy and consumer groups if the phase-out is accompanied with targeted compensation measures and an overarching strategy (Matthes et al. 2019).

Social and cultural challenges

In East Germany, the sudden structural break following the collapse of the GDR coupled with the closure of large parts of the mining industry left thousands of people without employment (Gürtler et al. 2020). As a result, many residents, often young and well-educated, left the region and chose to migrate to West Germany. This created a challenge for revitalizing the area due to a shortage of skilled workers and a declining labor force (Schwartzkopff and Schulz 2015; DIW et al. 2018). Additionally, the social policies and job creation programs that were implemented primarily consisted of temporary, low-skilled community service positions that failed to yield lasting positive effects (Ragnitz et al. 2022). To this day, the unemployment rate in Lusatia is almost twice as high as the national average.

This is supported by a study by Oei et al. (2020b) which has estimated the socio-economic effects of the lignite phase-out for the coming years in the lignite regions as well as for all of Germany. The authors show that, overall, lignite regions will experience a decline in employment. However, most of this effect can be attributed to demographic changes and migration of workers to other regions – both largely unrelated to the coal phase-out. However, negative effects of structural change are likely to manifest in the early stages of the future phase-out. Targeted labor market and social policies are therefore needed.

Moreover, local residents continue to exhibit a high level of skepticism about the coal phase-out compared to the rest of Germany (DIW et al. 2018). The lack of meaningful support indicates that previous measures have not effectively fostered social acceptance in the regions most affected by the transition. Further, while current support measures foresee the involvement and participation of local communities, researchers from the Ruhr Research Institute for Innovation and Structural Policy (RUFIS) show that these are not inclusive and transparent. The ambitious measures put forward have hardly been used, involvement is often only top-down in nature and a strategic approach to participation is missing (Goerke et al. 2023).

This analysis underscores the ongoing social challenges to phase out the remaining lignite capacity in East Germany by 2038 or at best, by 2030. The federal government has addressed these issues in the *Strukturstärkungsetz* (Investment Act for Coal Regions), where different programs and policies shall support a social, ecological, economic transformation of the entire region with the explicit aim to leave the region better off than before the coal phase-out (BMWK 2023b).

4.1.4. Opportunities

Along with the numerous challenges described above, several opportunities are present for the affected regions

and Germany as a whole, which are presented in the following section.

First and foremost, the targeted phase-out of coal contributes to achieving the German goal of net zero by 2045 because the shift from coal-based energy production to renewables leads to a substantial reduction in emissions. In 2020, lignite and hard coal were responsible for 66% of Germany's power generation related CO2 emissions alone. Moreover, the phase-out of hard coal reduces Germany's import dependencies. Today, hard coal accounts for 8% of the primary energy consumption and 9.3% of the generated power. Of the consumed hard coal, 93% were imported in 2020 (BMWK 2022b).

Second, former coal regions can utilize the switch to renewable energy sources to maintain their 'energy identity' by encouraging the development of the renewable energy sector. This can be particularly beneficial for employees who were previously engaged in the lignite sector but not directly involved in opencast mining, as they may find new employment opportunities within the renewable energy field (Honnen et al. 2023). This approach allows for the utilization of existing expertise in the energy sector, ensures the retention of the workforce within the region, and facilitates the development of a forward-oriented industry.

Third, the transition provides the opportunity to enhance the region's attractiveness for both companies and citizens. In areas where structural change policies were successful, the economy is more diversified, public service provision increased, knowledge enhanced and the overall quality of life improved. A good example is the Ruhr area, where, prior to the hard coal phase-out, not one university existed. Today, the presence of various universities and research institutes in the area has become an important driver for research, development, and innovation with an impact far beyond the region itself (Honnen et al. 2023). The newly established universities enhance the attractiveness for companies and citizens, increase location factors, stimulate the demand for highly skilled workers and foster research-based innovation. For citizens, soft location factors in the region are increased due to the renaturation or transformation of former industrial sites into landmarks (Brauers et al. 2018). These developments have the potential to counteract the unfavorable demographic developments described in the previous section.

Fourth, the retraining of former coal industry employees can help address the increasing shortage of skilled workers in Germany. However, these new work opportunities often have a lower wage level and are thus less appealing to the workers. Nevertheless, about two-thirds of the lignite workforce are currently above 45 years old. Following estimations of the German Institute for Economic Research (DIW), the majority can thus remain in employment in the lignite sector until they have reached retirement age as they can continue to work in the recultivation of former mining sites after the final phase-out (DIW et al. 2018).

4.2. Korea

4.2.1. Status Quo

As outlined in the first chapter, Korea has a history of economic development thanks to coal-fired power generation which has aided the country in gaining the status as an industrialized nation. Up to today, gaining and maintaining techno-industrial competitiveness is one of the country's key ambitions. In the early 2000s, Korea began to recognize the shift to green technologies as a means to boost overall economic competitiveness (Thurbon et al. 2021).

During discussions surrounding the *7th Basic Plan for Electricity Demand and Supply for 2015-2019*, announced in 2015, the idea of a reduction of coal-fired power plants was introduced for the first time. However, the coal trend remained, and the expansion of coal-fired power plants continued despite public health concerns surrounding particulate matter (Jeong et al. 2021).

In 2017, the government under President Moon began to shift policies towards increasing the rate at which coal-fired power plants should be removed (Jeong et al. 2021). As part of this policy shift, ten coal plants, which had been in operation for a minimum of three decades, were closed down. A combined capacity of 3,300 MW of coal-generated power was discontinued, and two units underwent a transition to gas. Furthermore, the Moon administration implemented a ban on the construction of new coal-fired power plants with exceptions for projects already in progress (IEA and KEEI 2023). As of 2022, 57 domestic coal-fired power units are in operation and 4 units are under construction. Chungnam has the largest share with 29 units, followed by Gyeongnam(14), Gangwon (6), Incheon (6) and Jeonnam (2) (IEA and KEEI 2023).

The coal power plants that have been shut down in operation so far have had a capacity of 500MW, while newer plants under operation have a significantly higher capacity of 1000MW. Accordingly, the overall capacity of coal-fired plants has not been reduced. In fact, in 2018, due to increases in coal-fired power generation, CO_2 emissions in the electricity and heating sectors reached 480% of 1990 levels, constituting the peak of Korean GHG emissions (Jones et al. 2024). Current plans, even if not enshrined in law, to retire or retrofit all existing coal plants to LNG by 2050 consider the current capacity of approximately 36.6 GW. However, due to the finalization of the ongoing construction of plants, capacity is expected to increase to 40GW by 2030. The *10th Basic Plan for electricity supply and demand* foresees that by 2036, thanks to continued closure of old plants, capacity will decrease again to 27.1GW (Lee 2024a).

According to the Korean Energy Economics Institute (KEEI), the government plans to reassign coal power plant workers to the construction and maintenance of transmission and distribution systems. These are expected to be high in demand given the expansion of LNG, hydrogen and ammonia-fueled power generation as well as renewables. Experience from those eight plants that have undergone closure has shown that 95% of the workforce was reassigned. The remaining 5% were retired or dismissed. The retention rate of workers directly employed by the power companies

was 100%. These workers are responsible for managing the main components of the plant such as generator, turbine and boiler. Workers employed at private companies were retained at a rate of 85% - 95%. This included workers responsible for maintenance, security, cleaning and other occupations. Furthermore, the government envisages the repurposing of coal power plant sites in a way that contributes to the local economy and electricity supply. Some designated coal power plants may continue as backup power supply while the remaining sites might be redeveloped as industrial complexes or tourist/ cultural sites (IEA and KEEI 2023).

Korea's coal mining sector is considerably small. The Korea Coal Corporation, also known as Korea Coal or KOCOAL, is a government-owned corporation that oversees the coal-mining industry in Korea. KOCOAL operates three domestic anthracite coal mines, producing approximately 0.8 million metric tons in 2022 (Statista 2023a). The peak of mining was in 1988 with 5.2 million tons (Global Energy Monitor 2021).

4.2.2. Drivers

There is an array of economic and socio-cultural factors with the potential to drive structural change in Korea. Identifying these driving factors is crucial for laying the groundwork to install effective policies that can help to enable the change needed.

As part of his foreign policy, President Yoon pursues the goal of turning Korea into a "global pivotal state". This entails serving as a responsible country that fulfills its international role and responsibility to help promote freedom, human rights, and the rule of law (Snyder 2023). Along the same lines, Korea - an OECD member since 1996 - has officially changed its status to a developed country in the United Nations Conference on Trade and Development (UNCTAD) in 2021. The country thereby officially recognizes its responsibility to adopt policies for the protection of the climate. With international pressure to strengthen climate protection measures rising each year, particularly for industrialized countries, Korea's climate policies can, at least in part, be seen as efforts to adhere to this pressure.

An important factor that gives momentum to the process of structural change in Korea is the call of several big coal regions in Korea to phase out coal burning and instead increase the deployment of renewable energy solutions. The four regions Chungnam, Gangwon, Jeollanam and Incheon Metropolitan City combined are host to 28GW out of the total of 36.4GW of coal capacity in Korea. The four regions (as well as 3 more) are members of the international Power Past Coal Alliance, a coalition of 48 national governments, 49 subnational governments and 71 global organizations as of March 2023 (Power Past Coal Alliance 2023).

The alarming level of air pollution in the country has increasingly become a public concern. In 2019 research showed that 81% of Koreans were concerned about levels of particulate matter in Korea (Gallup Korea 2019). The OECD reports that 42.7 deaths from ambient air pollution per 100.000 citizens occurred in Korea (OECD average being at 28.9) in 2019 (OECD 2023). The main causes for the high level of air pollution in Korea, and especially in Seoul, lie with traffic, fossil-fuel combustion as well as second-hand pollution from China that is transported by the wind over the Yellow Sea along with dust particles from Mongolian and Chinese deserts (Ministry of Environment 2016; Kim 2019). While little can be done to influence pollution wavering over from China, Korean politics can actively reduce the fine dust pollution created within its own borders by diesel engine cars and, notably, coal plants. For this reason, environmental NGOs like the Korean Federation for Environmental Movements (KFEM) have called for stopping plans to build new coal power plants and to reduce coal-fired electricity to below 20% by 2030 (Bicker 2019).

The Korean National Pension Service, the world's third-largest retirement fund has announced a withdrawal from investments in coal power, in an effort to make a sustainable transition (Roh and Kim 2021). However, until today they continue purchasing KEPCO bonds despite the utility's failure to align its policy with the Paris Climate Agreement (Solutions for our Climate 2023).

4.2.3. Challenges

Understanding potential challenges for successful structural change is as important as outlining drivers. Thus, this sub-chapter lays out socio-economic, societal, and political factors which could act as roadblocks to implementing structural change.

Political challenges

The political system in Korea itself presents a challenge to effective change in the long run. The presidential system with a maximum of one single term of five years with no re-election creates an ever-changing political landscape. Five years has proven to be barely enough time to enact medium-term policies let alone economic strategies for the coming decades, as is necessary for effective climate change mitigation (Joo et al. 2023).

Another aspect of the Korean political system that hinders structural change away from coal is the centralized decision-making power. Local governments in Korea do not have direct control over power plants within their boundaries and instead are dependent on rulings from the national government (Nhede 2021). Some local governments oppose the stance of the national government regarding prolonged coal burning and are calling for an earlier exit from coal (see 4.2.2 Drivers).

Socio-economic challenges

Increasing renewable energy capacity is the most crucial feat for realizing profound structural change away from fossil fuels. In order to substitute coal successfully with renewable energy, large-scale offshore wind as well as photovoltaic projects need to be implemented including agricultural PV in rural areas. This has led to conflicts between the Korean agricultural industry and the renewable energy industry. With

more than half of farmland being rented in Korea, landlords can decide to install solar panels on their land, leaving farmers without a livelihood. Critical voices such as Jungseop Kim, a senior researcher at the Korean Rural Economic Institute, have remarked that citizen participation was not adequately considered in the decision-making process for the responsible regulations which foresee the installment of substantial PV capacity on agricultural land. Moreover, concerns from farmers about solar energy threatening food security have been raised. Seeming evidence for this is drawn from the decrease of agricultural land in Korea due to land-use change resulting in a food self-sufficiency rate of approximately 45.8% in Korea in 2020 compared to 70% in the 1980s (Kang 2022). However, it seems that a combination of different factors such as an aging workforce and, related, a shrinking agricultural population and even climate change factors also play an important role in the decrease of available farmland (Kim 2023a).

A similar issue presents itself with regard to offshore wind power, one of the cornerstones of Korean renewable energy expansion goals (MOTIE 2020). The acceptance of offshore wind projects in affected communities is rather low because of conflicts of interest with different stakeholders. While the fisheries sector is concerned about decreased livelihood due to wind turbine construction within their territories, marine biologists worry about ecosystem destruction and a decrease in marine species as a result of construction noise, vibrations, and harmful substances used on the turbines (Oh et al. 2021). The tourism sector fears that offshore wind farms may lower the aesthetic value by blocking the ocean view, potentially causing economic damage to the industry (Kim et al. 2019). The ongoing necessary consultations of affected communities are effectively slowing down the process of offshore wind expansion.

In 2016, approximately 40% of photovoltaic and wind energy (onshore and offshore) development projects implemented in Korea were suspended due to objections from local inhabitants and stakeholder groups (Lee et al. 2023). Both of these examples demonstrate how top-down decision-making processes without adequate citizen participation lead to protests from stakeholders. This makes structural change challenging.

Another important socio-economic factor is the persistent fear of rising electricity prices among the Korean population. Korea has maintained a relatively cheap electricity price compared to other OECD countries. In 2019 the household electricity price was 105.0 KRW per kw/h. Since then, the prices were raised several times by KEPCO until in 2023, also due to the international energy crisis caused by the war of aggression of Russia against Ukraine, it was augmented to 149,8 KRW (0,10€) for households today (Woon 2024). This was met with strong criticism from society (Lee and Doyle 2022). An important reason for reservations from the public against renewable energy expansion is the persistent misconception that it will cause the electricity price to spark.

Public perception of climate change (policies)

One of the most pressing challenges that impacts political decision-making is the public perception of the issue. According to Choi Hyongjun (2020) 92.4% of the Korean public acknowledges climate change as a serious issue and according to (Roh and Kim 2021) 66.6% of the people support the energy transition to mitigate problems due to climate change. However, when ranking problems by urgency climate change ranks fourth behind air pollution, waste management and radioactive waste.

Differences were found according to ideology and political disposition. Among progressives and supporters of former President Moon the recognition of climate change as a problem was the highest. The same group has also indicated a greater tolerance for increased electricity bills to address the challenge of climate change while this tolerance was significantly lower among conservatives and non-supporters of Moon. Research findings indicate that a clearer stance from the Korean public along with a stronger recognition of the relationship between climate change and the energy economy, i.e., structural change from fossil fuels to renewable energy, would put more pressure on the government to move up the issue on the political agenda (Hyeonjung et al. 2023).

A survey – representative to the Korean population - investigating public opinion on the Korean government's plans to retire coal power by the Korea Energy Economics Institute (KEEI) has shown that 41% of participants are in favor of the current trajectory of phasing out coal by 2050; 19% would support the earliest phase-out possible; and 25% would be in favor of a later phase-out and a higher share of nuclear energy in the electricity mix. Importantly, 68.6% of respondents are in favor of a phase-out as long as electricity prices do not rise and only 9.3% support the phase-out regardless of rising prices. When asked, what the main reasons against a coal phase-out could be, 40% refer to energy security and 21% name rising electricity prices as main concerns (IEA and KEEI 2023).

4.2.4. Opportunities

This section is dedicated to reviewing the opportunities that the Korean state, and particularly its economy, can derive from implementing structural change.

Employment opportunities

The NGOs Climate Analytics and Solutions for our Climate have analyzed employment opportunities which could arise from replacing coal-fired power generation with solar, wind and storage. The results showed that a coal-to-renewables scenario could increase average job potential by almost 2.8 times between 2020 and 2030. The study finds that the overall job creation potential in the operation and maintenance of newly installed renewable and storage installations could counterbalance the job losses from closing all coal power plants across Korea by 2029. A crucial takeaway of the authors was that policies to facilitate green job creation are essential to generate support for a coal phase-out before 2030 in Korea (Climate Analytics 2021).

Health benefits

As was discussed above in Section 4.2.2. *Drivers,* health concerns due to air pollution, partly caused by coal plants on Korean land, play a central role for the Korean civil society. The Air Quality Life Index suggests that a decrease in fine dust would positively influence the average life expectancy of Koreans by 1.51 years, even more for citizens of the Korean capital Seoul. This number is more significant for the inhabitants of Seoul as particulate matter pollution is heightened in this location (Energy Policy Institute at the University of Chicago 2023). Decreasing particulate matter pollution would potentially decrease the number of premature deaths of Korean citizens by 2060, according to a report by the OECD (OECD 2023).

Economic benefits

Although a serious concern of Koreans is a potential rise in electricity prices due to the replacement of coal with renewable energies, latest research shows that switching to renewable power will save substantial costs in the long run. Research by IRENA demonstrates that almost two-thirds of renewable power added in 2021 had lower costs than the cheapest coal plants in G20 countries (IRENA 2022). The levelized cost of renewables continues to decrease (IRENA 2021). According to TransitionZero, the levelized cost of employing renewables plus storage of electricity is already well below the cost of gas-fired power in Korea (TransitionZero 2023).

Moreover, according to Carbon Tracker, all Korean coal power plants will become unprofitable before the end of their expected lifetimes, even under current environmental policies and power market regulations. This is due to the increasing need for greater power system flexibility and tightening regulations, which will reduce coal plant capacity factors. As a result, both operating and under-construction units will be unprofitable to run (Carbon Tracker Initiative 2023).

All of the findings above are reinforced by research done by Deloitte in 2021. Their modeling shows that Korea would reap significant economic benefits from climate action. This development would soar towards the middle of the century. They estimate that returns on capital and technology would outweigh the costs of structural adjustment. Their modeling framework was built on significant research on region-specific climate and economic impacts across Asia Pacific (Deloitte 2021).

Korean Electric Power Corporation (KEPCO), the state-owned electric utility responsible for the generation, transmission and distribution of electricity, has been heavily relying on expensive coal. This resulted in over 32.6 trillion KRW (US$25 billion) deficit in 2022, around 30% of which was directly attributable to coal power. Rather than making efforts to transition away from fossil fuels, the utility has been relying heavily on debt financing to cover its losses. A structural change away from coal would alleviate this public burden, dampening the tendency of rising electricity prices due to losses suffered by KEPCO (Solutions for our Climate 2022).

Increasing energy independence

Aside from the notable economic benefits that have been outlined above, it is not to be ignored that a structural shift of the energy economy from coal and gas to solar and wind will ensure Korea's independence from fossil fuel suppliers. The global energy crisis that was sparked by Russia's invasion of the Ukraine demonstrates the relevance of energy independence. Establishing a sensible mix of renewable energies combined with a stable grid and enough storage units can provide Korea with more independence from third countries.

Avoid stranded assets

Korea has a very high stranded asset risk compared to other industrialized countries due to regulatory structures which effectively guarantee high returns for coal generators, despite rather uneconomic production. These policy measures include: merit order being based solely on fuel costs; large capacity market payments; and compensation for carbon exposure and transmission restrictions. Under this system utility generators receive high cash flows, which would not occur in a market aligned with a below 2°C scenario. These "artificial" cash flows are at high risk of becoming stranded assets (Carbon Tracker Initiative 2019).

5 Lessons learned and Recommendations

This chapter provides conclusions and lessons learned from Germany's long trajectory of national coal exit and gives recommendations for Korea's coal phase-out as well as the future Korean-German cooperation on this topic.

Lessons learned from Germany's Coal Phase-Out

Substantial parts of the first section of this chapter are based on the study "Supporting the just transitions in Canada and Germany. Lessons from sixty years of coal phase-out in Germany" by Honnen et al. (2023).

Experiences made during the ongoing structural change of Germany's energy sector provide valuable lessons for policy-makers in third countries where similar undertakings are endeavored. Particularly the challenges that were identified in this study show that a just and in-time transition must be actively shaped using appropriate policy packages that combine forward-looking policies (e.g. to attract new industries) and reactive interventions (e.g. retraining and early retirement programmes for workers). Both horizontal and vertical policy integration is key, as structural change must take place across different policy areas (e.g. labour market policy and regional development policy) and levels of government (from local to national). Structural policy interventions must consider not only economic, but also social, ecological, and cultural aspects. Particularly labour market and social policies are crucial to cushion social hardships. This will in turn increase public support. When shaping the new economic organization of a former coal region it should be considered that diversification increases economic resilience. It is important to consider the regional context as there is no one-size-fits-all solution. Still, diversification can generally reduce the risk of structural breaks (Dahlbeck et al. 2022; Ragnitz et al. 2022). Different technologies or fuels (e.g. lignite and hard coal) may require different phase-out pathways and measures within one single country (Brauers et al. 2018).

Despite the valuable insights from Germany's trajectory of structural change, certain limitations in comparing Korea and Germany must be considered when reflecting on lessons learned. First of all, the situation that presented itself in East Germany, i.e. the breakdown of the entire economic and political system in 1989 and the following years, was unprecedented. Moreover, the extensive subsidies for hard coal which were in place for 60+ years and the related long-term phase-out are unlikely to be repeated by other countries. Today, renewable energy technologies are the cheapest means of energy production. With this recent economic development, a structural transformation to renewable energy is objectively cheaper and faces fewer obstacles than in past decades (Brauers et al. 2018).

Unlike Germany, where a strong coal mining industry was historically linked to prosperity and wealth, Korea has always had very low domestic coal production. Consequently, the shift away from coal is less complex in Korea, as coal has largely been imported from other countries. Structural change in Korea primarily involves phasing out coal power plants.

Recommendations for Korea's ongoing Coal Phase-Out

Phasing out coal is a key policy to ensure Korea's adherence to the 2015 Paris Climate Agreement. However, to achieve the pledged emission reductions, coal must be phased out much earlier than the current target date of 2050 (Kim and Lee 2023). A study by the Carbon Tracker Initiative finds that the renewables rollout can be accelerated beyond current government plans, to reach 40% by 2028, enabling an earlier coal phase-out. This is reinforced by their finding that all coal power plants will become unprofitable before the end of their expected lifetimes even under current environmental policies and power market regulations (Carbon Tracker Initiative 2023). Research from IEA and KEEI supports this by recommending an early retirement of coal power plants. While the technical lifetime of a coal plant is generally 40-50 years, its economic lifespan is only 20-30 years, which is the timescale over which capital invested is recovered. Therefore, an early retirement and potentially conversion of plants to another use can be an effective measure to accelerate structural change. To implement this policy, IEA and KEEI suggest considering financial incentives for power companies to accelerate coal switching (IEA and KEEI 2023).

One central recommendation for Korea is to invest in public support at the beginning of a policy design process for structural change. Public acceptance and support is a crucial factor for the implementation of said policy. Exchange with and inclusion of stakeholders should therefore be central to policy making and implementation at all levels. This must entail consultations as well as sharing information regularly and properly with all stakeholders. Workers and local communities should be invited as active participants, innovators, decision-makers, and beneficiaries of structural change (IEA and KEEI 2023). Particularly, education on the impacts of climate change and the need for structural change away from fossil fuels will enhance the support for such policies (Poortinga et al. 2019).

When designing transition policies to phase-out energy production via coal, it is important to avoid lock-in effects into other fossil fuels. Often, coal is replaced with natural

gas. This does not only hinder the decarbonization of the energy sector but also stands in the way of comprehensive structural change. Further, it is important to prepare the energy sector for a transformation. Timely investments in renewable energy sources and the grid will ensure energy security, grid stability and affordable energy prices for the population (Brauers et al. 2018).

To achieve a fair and just transition it is crucial to aim for the long-term retraining of workers. This entails aspects such as the relocation of employees to new sectors while subsidizing living expenses and education of workers over several years (Jeong et al. 2021).

Moreover, planning an adequate distribution of the financial costs of the transition early on among stakeholders is important. For instance, in East Germany the state had to shoulder the full costs of recultivation and to this date, the German federal government plans to provide substantial financial support to the most affected regions (Deutscher Bundestag 2020). Instead, a fair distribution of the financial responsibility is advisable. Future measures should be designed under the polluters-pay-principle, especially regarding the environmental damages and should be implemented before the closure of the last mines or power plants (Brauers et al. 2018).

Recommendations for future cooperation between Germany and Korea

With Germany and Korea aiming to reach climate neutrality by mid-century (2045 and 2050 respectively) while both economies still rely on coal combustion as a main energy source, it is beneficial to work alongside to phase-out coal as efficiently and swiftly as possible. The Korean-German Energy Partnership provides a platform to address difficulties related to the decarbonization of the countries' energy sectors and to work together towards halting climate change. By considering past policy experiences, mutual exchange and learning can support the countries in achieving their climate targets.

Germany's decade-long experience with phasing-out coal provides important lessons for accomplishing a just decarbonization of the energy sector. Lessons could be applied not only to the coal phase-out in Korea but also to the future phase-out of other fossil fuels, such as LNG, in both countries. Therefore, the following cooperation measures are recommended for both countries to profit from each other's experience:

- Conducting an expert trip to one of Germany's former coal regions to draw comparisons and lessons learned. This can particularly include insights on structural change and the repurposing of old coal power plant locations.

- Facilitating a bilateral exchange on policy measures supporting the phase-out of fossil fuels and a just transition in affected regions. The focus of the expert exchange could be on comparing existing policy measures in both countries, such as the amount of subsidies needed per MW taken off the grid or the policies required to establish alternative industries in former coal regions to avoid a drop in GDP.

- Conducting an expert workshop on the acceptance of transition policies. This event could be held with ministries and civil society to discuss how to raise awareness and acceptance of the transition away from coal. It could be organized as an in-person event in one of the affected regions in Korea, providing local actors from both countries the opportunity to exchange and network on the ground, potentially fostering a more in-depth conversation.

Another area for cooperation is the advancement of renewable energy sources with a focus on gaining social acceptance. Since fossil fuels must be substituted with renewable energy solutions, their acceptance in a country's population is not only important for realizing climate targets but also for achieving acceptance for restructuring measures related to the phase-out of fossil fuels. This could be achieved through:

- Continuing the existing cooperation and policy exchange on the integration of renewable energies into the electricity grid, including grid expansion, ways to minimize curtailment and the implementation of smart grids.

- Continuing the cooperation on acceptance of renewable energies in the civil society. These could take the form of workshops with civil society institutes, NGO's, local and regional governments and industry representatives on specific renewable energy technologies.

Continuing the exchange on energy efficiency through regular webinars on specific topics can complement the aforementioned activities, as increasing energy efficiency reduces the needed scale of renewable expansion and is crucial to achieving climate targets in all countries. Lastly, these activities should be complemented by cooperative efforts focused on communication and education regarding climate change and the energy transition. A deep understanding of the rapidly escalating impact of climate change on global living conditions is essential for the effective implementation of energy transition policies.

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