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Coal Transition Pathways in the European Union: Governance and Regional Transformation in Germany, Poland, and Czechia

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Abstract

The European Union's climate-neutrality objective is reshaping coal-dependent regions, but transition pathways differ according to historical coal dependence, institutional capacity, national energy systems, and regional economic structures. Coal phase-outs represent not merely a sector-specific energy shift, but a systemic socio-spatial transformation that reconfigures regional planning and territorial dynamics. This study examines how governance coordination, phase-out clarity, labour-market instruments, innovation strategies, and post-mining land reuse operate across three major Central European coal regions: the Ruhr Area (Germany), Upper Silesia (Poland), and the Moravian–Silesian Region (Czechia). It applies a qualitative, structured comparative review based on academic literature, policy and strategic documents, official statistics, and three flagship redevelopment cases within the framework of the EU RFCS-funded RAISING project. The comparison shows that the Ruhr Area's long-term, corporatist coordination has facilitated structural diversification and land reuse over several decades, though challenges regarding job quality and socio-spatial inequalities persist. In Upper Silesia, negotiated agreements foster regional consensus, while the multi-decade transition timeline reflects national energy-security priorities, supply-security constraints, and institutional complexity. In the Moravian–Silesian Region, early reactive restructuring in the 1990s contrasts with a more coordinated contemporary phase leveraging EU transition funding and strategic investment. Across all three cases, transition outcomes are mediated by place-specific conditions rather than formal closure speed alone. The study demonstrates that while core principles of early planning, multi-level coordination, and integrated asset reuse offer valuable insights, their application remains context-dependent, highlighting the necessity for place-sensitive European and national transition policies.



Academic Editor: Jianming Cai

Received: 6 August 2026

Revised: 9 September 2026

Accepted: 16 September 2026

Published: 19 September 2026

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Keywords: coal transition; just transition; coal-dependent regions; regional transformation; post-mining land reuse; multi-level governance; European Union

1. Introduction

Coal mining played a central role in the industrialization of Europe, shaping not only national energy systems but also the economic structures, settlement patterns, labour markets, and cultural identities of entire regions. Since the second half of the

twentieth century, however, declining competitiveness, changes in global energy markets, and increasingly ambitious climate policies have accelerated the contraction of coal extraction and coal-based power generation [1,2]. In response to the territorial and social consequences of this process, the European Commission launched the initiative Coal Regions in Transition (CRiT) in 2017 and subsequently incorporated support for carbon-intensive regions into the European Green Deal and the Just Transition Mechanism [3–5]. These initiatives recognize that moving away from coal is not solely a technological substitution within the energy sector, but a long-term process of regional economic, social, environmental, and spatial transformation.

In this article, “coal transition” refers to the managed phase-out of coal extraction and coal-fired power generation, alongside the associated restructuring of coal-dependent regional economies. “Green transition” is used more broadly to describe the movement towards a decarbonized energy system, economic diversification into knowledge-based and innovation-driven sectors, and the environmental remediation of post-mining land for low- or zero-emission purposes. To ensure equity throughout this transformation, a “just transition” adds an explicitly social and political dimension by considering how the benefits, costs, and decision-making processes associated with this transformation are distributed among workers, communities, firms, and territories. The just-transition literature therefore emphasises not only employment protection and retraining, but also procedural participation, recognition of place-specific identities, and the risk that existing inequalities may be reproduced through economic restructuring [6–8].

Three complementary perspectives inform the comparison developed in this study. First, the just-transition perspective draws attention to the distributional and social consequences of coal decline, particularly for workers and communities whose livelihoods and identities remain connected to extractive industries. Second, a multi-level governance perspective highlights the coordination required among European, national, regional, and local institutions, as well as industry, trade unions, and civil society. Third, regional path-development approaches emphasise how inherited industrial structures, skills, infrastructure, and institutional capacities can either constrain transformation or support the creation of new development trajectories [9,10]. Taken together, these perspectives suggest that regional transition pathways cannot be assessed solely according to the speed of coal phase-out, but must also be examined through their starting conditions, governance arrangements, labour-market instruments, innovation strategies, and post-mining land reuse approaches.

The European Union provides a shared climate-policy and funding framework for coal regions, but it does not dictate a uniform transition pathway. Under Article 194 of the Treaty on the Functioning of the European Union (TFEU), member states retain authority over their national energy mix, while their coal regions differ considerably in terms of coal dependence, economic diversification, institutional capacity, and energy-security concerns [3]. Germany ended domestic hard coal extraction in 2018 and legislated the phase-out of coal-fired power generation by 2038, with an earlier 2030 target for lignite operations in the Rhineland [11,12]. Poland’s hard coal mines are scheduled to close gradually by 2049, while no definitive national lignite phase-out date has been established [12]. In Czechia, hard coal extraction ended in early 2026, and the phase-out of lignite mining and coal-fired power generation is planned for approximately 2033 [12,13]. These timelines reflect not only different levels of political ambition, but also distinct historical trajectories, domestic energy resources, labour-market structures, fiscal capacities, and geopolitical energy security considerations.

Existing studies have examined individual coal regions, national coal phase-out policies, labour-market consequences, and specific redevelopment initiatives. However, these

strands of analysis are rarely brought together within a common comparative framework linking initial regional conditions, governance arrangements, social and labour instruments, innovation capacity, and post-mining land reuse. The Ruhr Area in Germany, Upper Silesia in Poland, and the Moravian–Silesian Region in Czechia provide representative cases for such a comparison. All three are major Central European coal regions operating within the EU policy framework, but they differ substantially in the timing and drivers of coal decline, institutional coordination, economic structures, and the maturity of their redevelopment processes. The individual redevelopment projects examined in each region serve as illustrative cases of post-mining land transformation rather than as representative measures of national or regional transition performance.

This comparative study was developed within the thematic scope of the RAISING project, which brings together partner institutions from Germany, Poland, and Czechia to foster transformation awareness in hard coal and lignite regions and to support new visions for their future development [14]. The project provided the collaborative setting and region-specific expertise through which the three cases were identified and examined. However, the evidence analysed in this article consists of the academic literature, policy and strategic documents, official statistics, and institutional sources described in Section 2.

Against this background, this article addresses the following research question: How do governance coordination, coal phase-out clarity, labour-market instruments, innovation strategies, and post-mining land-reuse approaches differ across the three selected EU coal regions, and what context-dependent lessons emerge from their transition pathways? To answer this question, the study applies a structured, focused comparison based on academic literature, policy and strategic documents, official statistics, and illustrative redevelopment cases. Rather than ranking or establishing direct causal links, the analysis identifies recurring patterns, contextual constraints, and key transition dynamics. The remainder of this article is structured as follows: Section 2 explains the comparative research design, case selection, and analytical framework; Section 3 presents the country and regional evidence and develops the cross-case comparison; Section 4 discusses the findings in relation to the academic literature, including their explanatory implications and transferability; and Section 5 concludes with policy considerations, study limitations, and directions for future research.

2. Materials and Methods

This section outlines the comparative methodology, theoretical framework, data sources, and research procedures used to analyse regional transformation pathways across Central European mining basins. The study applies a qualitative, structured, focused comparison to three major coal regions: the Ruhr Area in Germany, Upper Silesia in Poland, and the Moravian–Silesian Region in Czechia. Operating within the shared policy and funding framework of the European Union, including the European Green Deal and the Just Transition Mechanism, these regions share deep industrial legacies while exhibiting distinct coal-dependence profiles, governance arrangements, and phase-out timelines. This combination of structural similarities and contextual variations provides an empirical basis for identifying cross-regional patterns, institutional constraints, and transferability lessons across European coal transitions.

2.1. Comparative Design and Case Selection

This study adopts a structured, focused comparative design to examine coal-transition pathways in three Central European regions: the Ruhr Area in Germany, Upper Silesia in Poland, and the Moravian–Silesian Region in Czechia. This approach applies a common

set of analytical dimensions to each case while allowing the historical, political, economic, and institutional context of each region to be considered. The analysis is qualitative and interpretative. It does not assign numerical scores or seek statistical generalisation across European coal regions.

The three regions were selected purposively because they combine important common characteristics with substantial variation in their transition trajectories. All three have long histories of hard coal extraction, have experienced extensive industrial restructuring, and operate within the broader climate-policy and funding framework of the European Union. At the same time, they differ in the timing and drivers of coal decline, their current dependence on coal, the clarity of national phase-out commitments, their governance arrangements, and the maturity of their regional redevelopment processes. This combination provides a suitable basis for examining how comparable coal-related legacies are addressed under different political, economic, and institutional conditions.

The principal unit of comparison is the coal region embedded within its respective national policy context. National legislation, energy strategies, and phase-out commitments are used to describe the broader conditions under which regional transformation occurs. Labour-market developments, economic diversification, environmental rehabilitation, and post-mining land reuse are interpreted primarily at the regional level. This distinction avoids treating national policy decisions, regional socio-economic trends, and individual redevelopment projects as directly equivalent forms of evidence.

One redevelopment initiative from each region is included to illustrate how former mining land and infrastructure have been repurposed in practice: MARK 51°7 in Bochum, the Wieczorek Mine in Katowice, and the Karolina site in Ostrava. These initiatives were selected because they constitute prominent and comparatively well-documented examples of post-industrial redevelopment in their respective regions. They are treated as illustrative cases rather than as representative measures of regional or national transition performance. Their different historical trajectories, intended functions, and stages of implementation are considered when interpreting their comparative relevance.

2.2. Analytical Framework

The analytical framework combines three complementary theoretical perspectives: just transition, multi-level governance, and regional path development. Just-transition research provides the basis for examining labour-market protection, stakeholder participation, and the distribution of transition costs and opportunities. Multi-level governance directs attention to the allocation and coordination of responsibilities among European, national, regional, and local institutions, as well as industry, trade unions, and other stakeholders. Regional path-development research provides a basis for examining economic diversification, innovation, inherited industrial assets, and the reuse of post-mining land and infrastructure [6–10].

Figure 1 presents how these theoretical perspectives and the documentary evidence are connected to six dimensions applied consistently across the three regional cases. The framework distinguishes the starting conditions under which coal transition occurs, the governance capacity through which it is managed, the social, economic, and spatial instruments used to support regional transformation, and the persistent challenges and regional transition patterns observed in each case. It is used to organise and interpret the available evidence and does not represent a quantified or statistically tested causal model.

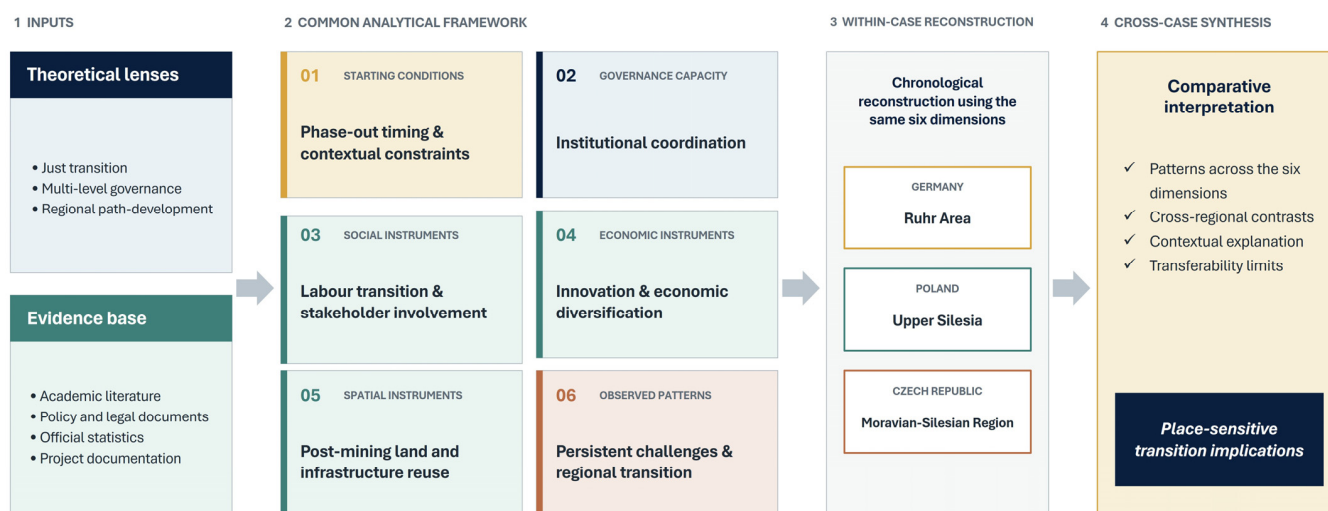


Figure 1. Analytical framework used for the structured, focused comparison of coal-transition pathways. The arrows indicate how theoretical perspectives and documentary evidence were organised through six common analytical dimensions, within-case reconstruction, and cross-case synthesis. They represent the analytical workflow and do not imply numerical scores or statistically tested causal relationships.

The first analytical dimension, phase-out timing and contextual constraints, captures the clarity and predictability of mine-closure and coal-exit commitments together with the historical, economic, and energy-security conditions surrounding them. The second dimension, governance capacity, examines how responsibilities are distributed and coordinated across governance levels and among public authorities, industry actors, trade unions, and other stakeholders.

The next three dimensions address the principal instruments of regional transformation. Social instruments include labour agreements, early-retirement schemes, retraining, mobility support, social dialogue, and documented forms of stakeholder participation or contestation. Economic instruments include investment in research and education, innovation strategies, investor attraction, industrial diversification, and the development of alternative regional economic pathways. Spatial instruments cover environmental rehabilitation and the adaptation of former mining land and infrastructure for economic, cultural, energy-related, environmental, or public functions.

The final dimension examines persistent challenges and regional transition patterns. These include documented labour-market developments, job-quality concerns, socio-spatial inequalities, implementation gaps, institutional constraints, and differences in the maturity of redevelopment processes. The six dimensions translate the theoretical perspectives into aspects that can be examined consistently across the cases. They provide a common structure for organising the evidence rather than variables for calculating a composite score or ranking the regions according to a single definition of transition success.

2.3. Documentary and Statistical Source Base

The comparison draws on four categories of secondary evidence: (1) peer-reviewed academic literature; (2) European, national, and regional policy and strategic documents; (3) official statistical data; and (4) institutional and project documentation concerning the selected redevelopment initiatives.

Academic publications were used to establish the theoretical context and interpret regional transition processes. Policy and legal documents were used to identify formal phase-out commitments, governance arrangements, funding instruments, and labour-transition measures. Official statistical sources provided descriptive information on coal

production, mining employment, unemployment, and other relevant socio-economic developments. Institutional and project sources were used to reconstruct the histories, stated objectives, implementation status, and intended functions of the illustrative redevelopment initiatives.

Sources were retained when they referred directly to at least one of the selected countries or regions, addressed one or more of the six analytical dimensions, and originated from an identifiable academic, governmental, statistical, or institutional source. General commentary without a traceable evidence base was not used to support comparative claims. Sources that did not distinguish adequately between national and regional conditions were used only for broader contextual information. The documentary review was structured around the research question but was not intended to constitute an exhaustive systematic review of all literature concerning European coal transitions.

Different source types were used for different evidentiary purposes. Official statistics and legal documents provided the basis for production, employment, and formal policy timelines, while peer-reviewed studies supported the interpretation of governance arrangements and socio-economic developments. Project documentation was used primarily to describe the status and objectives of the redevelopment initiatives; statements concerning planned investments or anticipated outcomes were therefore distinguished from documented results. Where possible, important factual and interpretative claims were cross-checked using more than one type of source.

The available statistical series differ among the three regions in their starting years, territorial definitions, and indicator availability. Regional data trends presented in Section 3 are consequently used primarily to reconstruct developments within each regional case rather than as a harmonized dataset for direct quantitative comparison. Their graphical presentation and terminology are harmonized where possible, while remaining differences in temporal and territorial coverage are acknowledged when interpreting the results.

2.4. Comparative Procedure

The analysis was conducted in three stages. First, a chronological within-case reconstruction was developed for each region. This reconstruction covered major changes in coal production and mining employment, relevant policy decisions, labour-market developments, institutional arrangements, and important redevelopment interventions. The purpose of this stage was to identify the historical sequence and context of each regional transition.

Second, the evidence from each case was organised according to the six analytical dimensions presented in Figure 1. A common evidence structure was used to distinguish national policy commitments from their regional implementation and to separate documented developments from planned or anticipated outcomes. Particular attention was given to the different maturity levels of the redevelopment initiatives and to the distinction between direct statistical evidence, interpretations reported in academic studies, and objectives stated in policy or project documents.

Third, the three cases were compared across the six dimensions to identify recurring patterns, cross-regional differences, contextual constraints, and limits to the transferability of individual transition approaches. Qualitative interpretations were based, where possible, on convergence among academic studies, official statistics, policy documents, and institutional sources. No numerical scores were assigned, and the comparison was not used to establish a ranking of regional transition success.

The study does not directly measure public attitudes or social acceptance through surveys, interviews, or other primary data. References to the social dimension are therefore limited to documented evidence of institutionalised social dialogue, stakeholder alignment,

labour conflict, or public contestation. Similarly, the temporal association between governance arrangements, policy interventions, and socio-economic developments is interpreted cautiously and is not treated as proof of direct causality. The resulting cross-case findings are consolidated in the comparative table presented in Section 3.

3. Results

This section presents the empirical findings of the comparative assessment across the three coal regions: the Ruhr Area (Germany), Upper Silesia (Poland), and the Moravian–Silesian Region (Czechia). To structure the case studies while addressing the six analytical dimensions established in Section 2, each region is evaluated across four thematic pillars: transition governance, social and environmental adjustment, economic diversification, and spatial transformation through flagship case studies. These findings are then synthesised in a cross-case comparison across all six dimensions.

3.1. Germany: Ruhr Area

Germany’s coal transition combines structured policymaking with negotiated agreements among federal authorities, regional governments, and industry. After ending domestic hard coal mining in 2018, the country adopted the Coal Phase-Out Act, which sets a complete exit from coal-fired power generation by 2038. More recently, North Rhine–Westphalia and the federal government agreed with RWE AG to advance the lignite phase-out in the Rhineland to 2030. The Act foresees a gradual reduction in lignite- and hard coal-fired power stations ahead of the full phase-out in 2038. Lignite plants will be closed under negotiated agreements with operators, while hard coal-fired power units will exit through a tender system that provides financial compensation until 2026, after which no compensation is available [11,15].

During the 1950s, the hard coal mining industry was one of the core sectors for Germany’s industrial economy, producing 150 million tons of hard coal annually with 600,000 workers across 173 mines, especially shaping the economic, social, and cultural fabric of the Ruhr Area. However, the rise in oil as a dominant energy source, increasing volumes of cheap coal imports, and the global availability of less expensive steel in the 1960s and 1970s triggered the decline of coal, steel and related industries. This industrial contraction, alongside the sharp increase in unemployment throughout the 1980s, created significant socio-economic challenges, making the need for sustainable regional redevelopment and long-term transition increasingly urgent [2,16]. Building on this long-term structural decline, final closure of all active domestic hard coal mines occurred in 2018 as a result of the Hard Coal Financing Act enacted in 2007 [17]. Figure 2 illustrates the history of hard coal mining in Germany and the Ruhr Area, highlighting key trends in production, employment, and unemployment [18–22].

Transition Governance and Strategic Planning: The Ruhr Area is a key example of a decades-long, market-driven structural transformation that is still ongoing. Unlike Germany’s current lignite regions, where the phase-out is politically coordinated through the Coal Commission and the Act to Reduce and End Coal-Fired Power Generation, mandating a complete coal exit by 2038, the Ruhr’s transition unfolded over a much longer period and was driven largely by economic pressures rather than through a fixed political framework [15,23].

A major policy milestone for the hard coal phase-out was reached in 2007, when the Federal Government, the states of North Rhine–Westphalia and Saarland, the RAG Corporation, and the mining union IGBCE agreed to terminate hard coal subsidies by the end of 2018. This decision, formalized in the Hard Coal Financing Act, initiated the final stage of the hard coal exit. To ensure a socially and environmentally responsible phase-out, the RAG

Foundation was established to manage mine closures and finance the perpetual obligations including mine water management, polder measures, and groundwater purification [17].

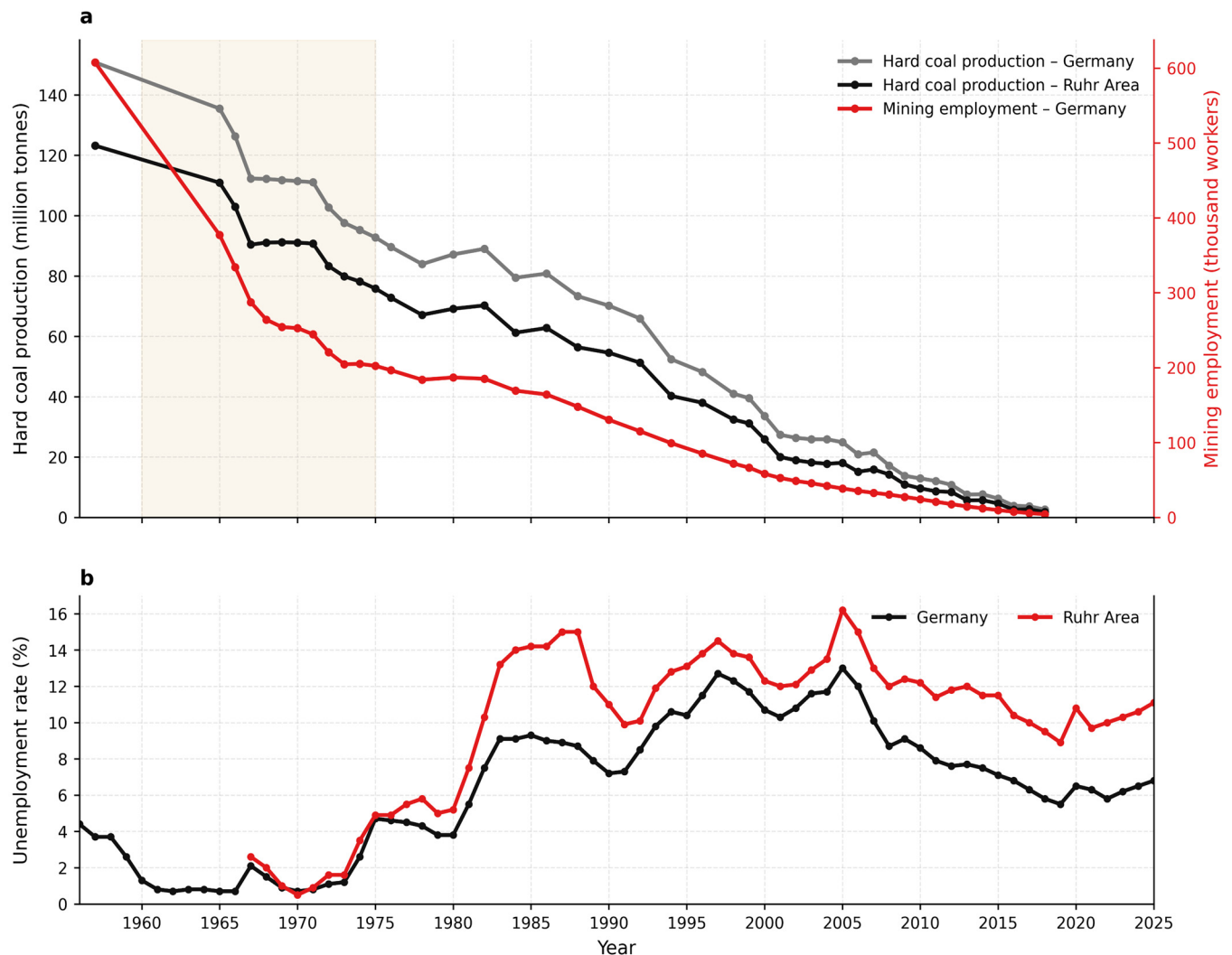


Figure 2. History of hard coal mining and key socio-economic indicators in Germany and the Ruhr Area: (a) Hard coal production and employment 1957–2018 [18,19]. (b) Unemployment rate 1956–2025 [20–22]. * Data for Germany refers to the former Federal Republic of Germany (West Germany) for 1956–1990 and reunited Germany from 1991 to 2025.

Furthermore, programmes such as Konzept Ruhr and the Coal Brownfield Agreement allowed Ruhr municipalities to access European regional development funds, redevelop former mining sites, increase regional attractiveness for investors and collaborate closely to realise a successful transition. The Regional Association Ruhr (RVR) has played a central role in integrating spatial planning, economic development, and the reuse of post-mining lands [24,25].

Social Acceptance, Labour Transition, and Environmental Rehabilitation: Social acceptance of the Ruhr's coal transition has been shaped by long-standing, multi-level collaboration among the federal government, regional states, municipalities, labour unions, employers' associations, mining companies, and civil society organisations. This corporatist governance model played a central role in ensuring a socially just transformation [26]. As coal production declined, local, regional, and national governments worked together to manage unemployment and retrain workers, attract new corporations, invest in infrastruc-

ture as well as in universities and research centres, and improve the general quality of life in the region.

Through the adoption of a gradual and socially oriented approach by policymakers, miners were protected via negotiated labour agreements, early-retirement schemes, internal mobility programs, and retraining initiatives. Even though coal-related industries experienced significant job losses and unemployment exceeded 15% in some municipalities, social dialogue mitigated social conflict and strengthened public acceptance of the transition [27].

Innovation and Future-Oriented Development: Economic restructuring in the Ruhr Area is characterised by the long-term transition from a mono-industrial coal- and steel-region to a diversified service- and knowledge-based economy. The establishment of universities and technical colleges in the 1960s marked a turning point, which transformed the Ruhr into the most-densely equipped higher education region in the EU, and laid the foundation for knowledge-intensive industries [27]. Building on this institutional change, the region's economy has diversified into growth sectors such as health services, the region's largest employer today, logistics, IT, education, and science, collectively supporting the Ruhr's repositioning as a hub of knowledge and technology [28].

The RVR has played a central role in redeveloping former steel and mining sites into areas for new business, cultural events, and leisure experiences. For instance, the Industrial Heritage Trail with its 25 anchor points, including the Zollverein World Heritage Site in Essen, demonstrates how culture, education, and tourism have become engines of structural change. This coordinated governance model, which integrates spatial planning, social dialogue, and innovation, has been widely recognised as a key factor enabling the transformation of the Ruhr region into a sustainable, liveable industrial region [29].

However, several municipalities still face unemployment rates above the national average, and many new jobs created in the service sector offer lower wages and productivity compared to the former mining industries. These socio-spatial inequalities demonstrate that, despite remarkable progress, the Ruhr's transition is not yet fully inclusive.

Case Study “MARK 51°7—transforming an industrial production site into an innovation district”: The transformation of the former Opel manufacturing site in Bochum into MARK 51°7 is one of the Ruhr area's most significant transition projects and a prominent example of innovation-driven redevelopment. Following the closure of the Dannenbaum colliery in 1958 and the subsequent decline of coal and steel industries, regional authorities sought to attract new industries. This led to negotiations with Adam Opel AG, which resulted in the construction of Opel's largest European production plant on the former mine site. For several decades, the plant provided thousands of jobs and helped stabilise the local economy [30]. Following the closure of the Opel plant at the end of 2014, Bochum faced once again major socio-economic uncertainty. With significant state support, the City of Bochum, together with regional development partners through Bochum Perspektive GmbH, initiated a comprehensive redevelopment strategy. The result is MARK 51°7, a technology and innovation district covering approximately 70 hectares and designed to host high-tech industries (such as cybersecurity and automotive), research institutes, and university facilities. Figure 3 summarises the transformation of the MARK 51°7 site from coal extraction through automobile manufacturing to its current innovation-oriented redevelopment [31]. Over 99% of the site has been marketed, with projections of employing up to 13,000 people over time [32,33].

GERMANY — MARK 51°7, BOCHUM

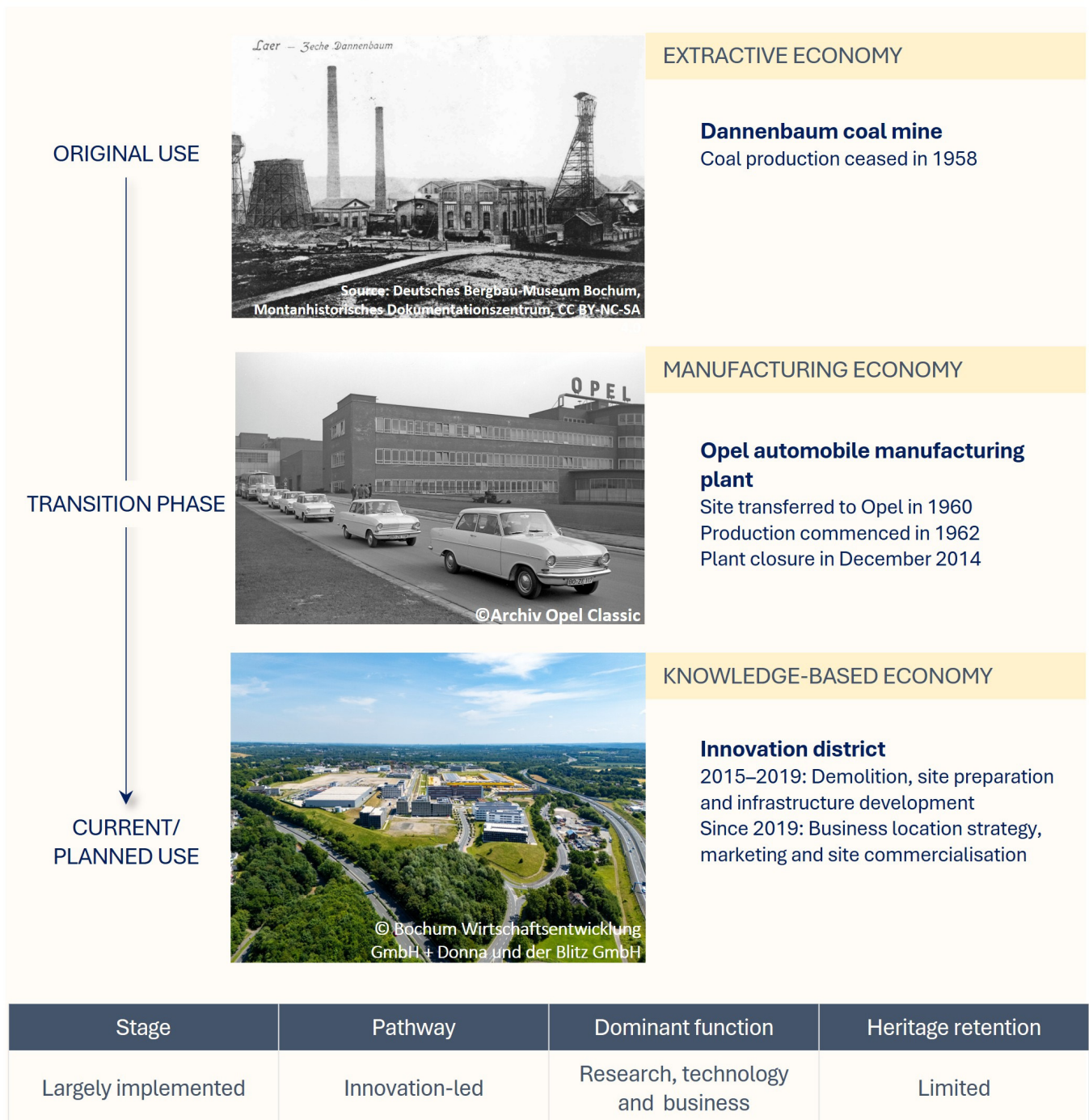


Figure 3. Transformation pathway of the MARK 51°7 site in Bochum, Germany: from coal mining and automobile manufacturing to an innovation campus.

The use of mine water from the former Dannenbaum colliery as a geothermal energy source is the highlight of the project. Mine water of approximately 27–28 °C will be extracted from a depth of ~840 m to provide heating in winter, while during the summers, water of around 17 °C will be pumped from ~340 m deep for cooling. Following the successful completion of drilling in 2022 and the installation of central mine water pumps in late 2025, the facility entered its commissioning phase in 2026. Once fully operational, this system will supply approximately 70–75% of the heating and cooling requirements of the buildings on the site. As the largest mine water energy project in Germany, it serves

as a notable example of how post-mining infrastructure can be repurposed to provide climate-neutral energy solutions [34–36].

In general, MARK 51°7 shows how a former coal and automobile manufacturing site can be transformed into a future-oriented innovation campus through coordinated governance, strategic investment, and the integration of low-carbon technologies. It stands as a leading example of how the transition of post-mining areas can support regional economic diversification while contributing to broader European climate and sustainability objectives.

3.2. Poland: Upper Silesia

Poland faces the most challenging coal transition, with coal still generating approximately 56% of its electricity in 2024, and employing the largest coal workforce in Europe [37,38]. The Polish economy therefore remains highly emission-intensive due to its reliance on coal. While hard coal mines are scheduled to close by 2049, no lignite phase-out date has been defined, and the transition process is impeded by significant political and economic barriers [12,39].

Transition Governance and Strategic Planning: Polish transformation solutions are characterised by a multi-level system of transition governance that is well documented formally, but institutionally fragmented. Energy-, climate-, and development-related frameworks are defined centrally through national policies, while the actual operationalisation of the transformation process is largely delegated to the regions.

At national level, the key strategic documents are Poland’s Energy Policy and the National Energy and Climate Plan for 2021–2030, which incorporate the objectives of the European Green Deal [40]. Poland’s Energy Policy until 2040 (PEP2040), updated in 2022 in response to the energy crisis and the REPowerEU Plan, reflects the government’s decision to terminate imports of energy resources from Russia as rapidly as possible [41,42]. The PEP2040 strengthens the role of renewable energy sources, aiming for a 50% share of renewables in the energy mix by 2040, and promotes the development of nuclear power.

The second key document is the National Energy and Climate Plan for 2021–2030 (KPEiK), which was amended in 2024 in line with the “Fit for 55” targets [43]. The Plan sets national targets for emission reductions, renewable energy development, energy efficiency, and energy security, while also addressing environmental objectives and the transition towards a circular economy.

A bridge between the short-term resilience of coal regions and medium-term transformation is provided by the National Recovery and Resilience Plan with the REPowerEU component [44]. It has opened up new financing opportunities, particularly for investment in distributed energy systems, energy storage, and the decarbonisation of district heating.

At regional level, the main actors in the transformation process are the regional governments of the five coal regions: Silesian Voivodeship as the core mining region, together with Małopolskie, Wielkopolskie, Lower Silesian, and Łódzkie Voivodeships. These regions manage European funds based on Territorial Just Transition Plans approved by the European Commission in 2022, as well as regional development strategies and operational programs [45].

Social Acceptance, Labour Transition, and Environmental Rehabilitation: For decades, hard coal mining was one of the key sectors of the Polish economy and one of the country’s largest employers. Since 1990, the sector has undergone the most extensive restructuring in the history of Polish industry, both in terms of employment reduction and the pace of mine closures. These changes were driven by a combination of

internal factors related to Poland's transition to a market economy after 1989 and European Union climate policy, which after 2010 became a key driver accelerating structural transformation in the sector. Figure 4 illustrates the parallel decline in coal output and employment. Production fell from 147 Mt in 1990 to approximately 55 Mt in 2023, while the workforce contracted from 416,000 to 72,000, representing an 82% decrease, both reflecting the combined pressure of market liberalisation, EU climate policy, and declining competitiveness of domestic hard coal.

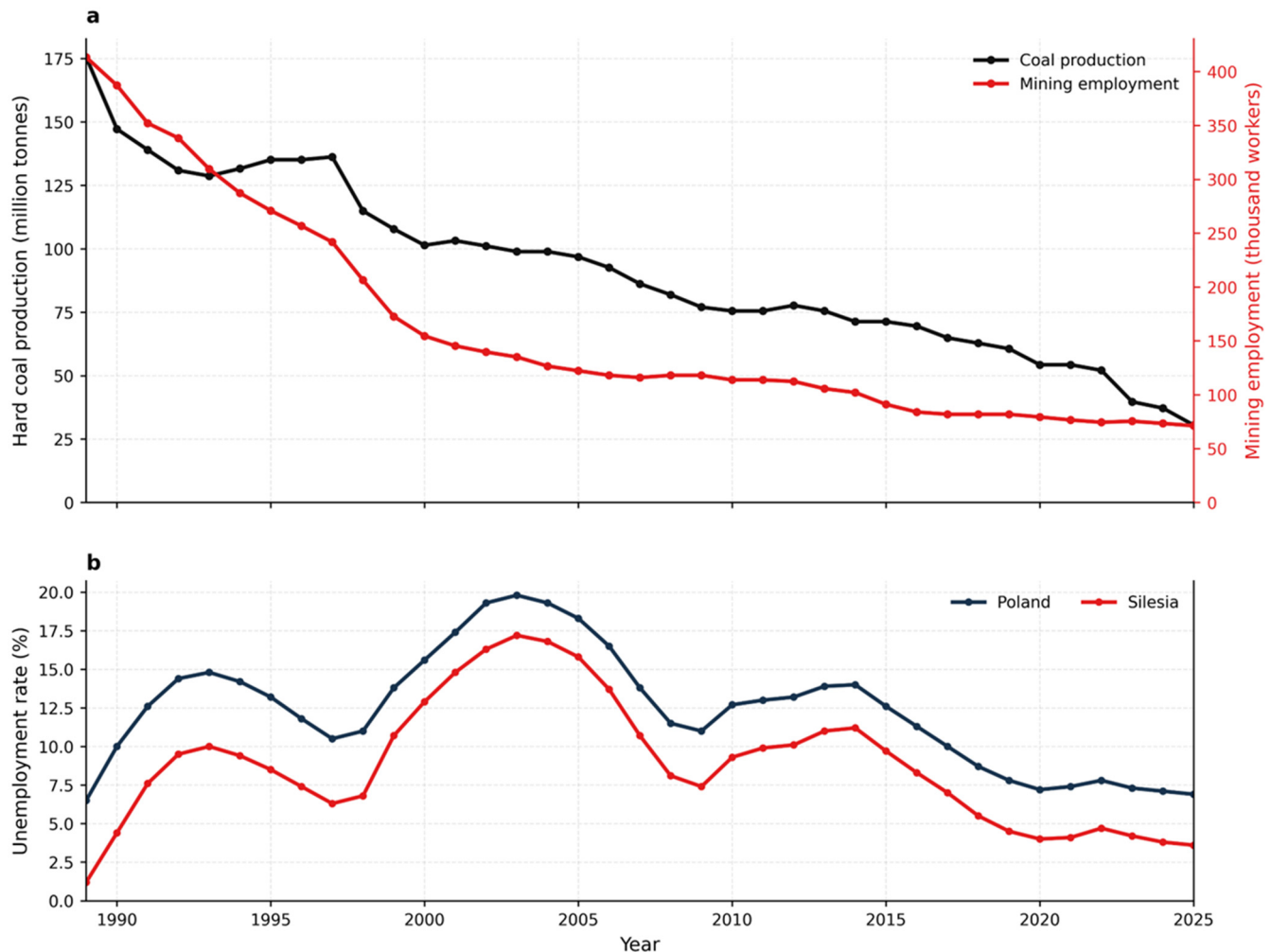


Figure 4. Changes in Polish hard coal mining between 1989 and 2025: (a) Hard coal production and employment [46]. (b) Unemployment rate in Silesia and Poland [47]. Due to the administrative reform, the Silesian Voivodeship in its current administrative form has existed since 1 January 1999. For the years 1989–1998, the data provided by Statistics Poland (GUS) refer to the Katowice Voivodeship.

Nevertheless, unemployment in Silesia remained below the national average for most of this period, and the elimination of mining jobs did not mechanically translate into a sustained rise in unemployment. While national labour market conditions improved after EU accession in 2004, structural unemployment in the most coal-dependent municipalities remained persistently above the national average [48,49]. As shown in Figure 4, two peaks in the unemployment rate are visible: at the turn of the 1990s and during the years 2002–2004, which partially coincide with successive waves of mine closures. However, the rapid decline in unemployment following each of these episodes suggests that the region was able to absorb the laid-off workers effectively, owing in part to severance packages, early retirement schemes for miners, and the gradual diversification of the local economy.

In regional terms, Upper Silesia remained one of the country's principal industrial cores, although the pace of GDP growth and labour market recovery was uneven. Over the course of 35 years of structural transformation associated with the closure of mines and heavy industry, the region has consistently remained the second-largest contributor to Poland's GDP, currently accounting for approximately 12% of the national total [47]. At the beginning of the transition period, between 1989 and 1998, the former Katowice Voivodeship generated around 15–15.5% of Poland's GDP, reflecting its dominance as the country's principal mining and metallurgical centre. The GDP of the Silesian Voivodeship increased from PLN 51 billion in 1995 to more than PLN 205 billion in 2012. However, during the 1990s, the growth rate was noticeably lower than the national average, as the closure of mines and steelworks constrained economic dynamics. In 2000, the region's share of Poland's gross value added amounted to 13.26%, but it has been gradually declining ever since. Between 2005 and 2012, the average annual GDP growth rate was 6.6% for the Silesian Voivodeship, compared with 7.15% for Poland as a whole [50,51]. As can be seen, during periods of economic prosperity Poland grows faster than the Silesian Voivodeship, while during crises Silesia proves to be more vulnerable due to its industrial exposure. GDP per capita remains above the national average, but the gap has been narrowing gradually, demonstrating that the region is relatively losing its economic importance compared with faster-growing metropolitan areas. It helps explain why the Polish transition continues to be socially and politically sensitive. Regional GDP dynamics reflect these structural changes. During the 1990s, the contribution of Silesian Voivodeship to national GDP declined relative to that of other voivodeships, as coal-related value added contracted sharply. However, economic diversification, particularly in the service sector, the automotive industry, and advanced manufacturing, enabled the region to stabilise its economic base by the mid-2000s.

In subsequent phases, restructuring of Poland's hard coal mining sector became less sharp but more prolonged, compared with the rapid transformations of the 1990s. Social impacts included continuous employment decline, although this process was gradually mitigated by social protection instruments, such as the Miners' Social Package, and by European funds supporting regional economic diversification. Retention of some mines and restructuring of large mining enterprises enabled part of the workforce to find alternative employment or participate in retraining programmes, particularly after Poland joined the European Union and structural funds were launched. Nevertheless, mining regions continued to face structural challenges, including limited labour mobility, population drains, and the need for broader local economic restructuring, despite emerging examples of reinvestment and development of new economic sectors. From an environmental perspective, reduced extraction and integration of European climate policies contributed to lower environmental pressure, although the reclamation of post-mining land progressed unevenly [52,53].

The Social Agreement, negotiated among the government, trade unions, and representatives of the coal sector, came into effect in 2021. It defines the framework for the transformation of hard coal mining in Poland and sets out a detailed process for the gradual phase-out of coal mines by 2049, accompanied by a comprehensive package of social safeguards and support measures for mining regions [54].

On 4 December 2025, the Polish Parliament adopted an amendment to the Act on the Functioning of the Mining Sector, which establishes the legal framework for the transformation of coal mining by aligning legislation with the current phase-out model and implementation of the provisions of the 2021 Social Agreement. It provides social support for miners leaving the sector, enables the financing of mine closures from the state budget,

and aims to prevent financial difficulties for mining companies such as Polska Grupa Górnicza (PGG) and Jastrzębska Spółka Węglowa SA (JSW) [55].

Innovation and Future-Oriented Development: A key precondition for a successful green transition is innovation, which is developing unevenly across Polish coal regions. Regional innovation strategies, such as the Silesian Voivodeship Development Strategy “Silesia 2030: A Green Silesia” [56], together with Territorial Just Transition Plans, seek to translate these objectives into concrete projects in renewable energy, the circular economy, hydrogen technologies, and Industry 4.0. However, their effectiveness depends on the institutional capacity of regional authorities and the quality of local partnerships capable of implementing such projects.

Renewable energy sources, specifically photovoltaics, and wind farms located on post-mining land, are considered key sectors for future growth, alongside advanced environmental services as well as technologies, energy storage and the development of hydrogen technologies. Post-mining sites are increasingly recognised as valuable spatial resources for such investments. Nevertheless, the absence of a single strong coordinating operator may pose a risk of project fragmentation and the underutilisation of the full innovative potential of these areas, for example in relation to the use of energy from mine water. Further development therefore requires the integration of innovation, energy, labour market, and land reclamation policies into coherent territorial packages, as well as measures to strengthen the role of research, science, and business as the backbone of regional “living laboratories” of transformation [57,58].

Case Study “Katowice Nikiszowiec—between tradition and innovation”: The Nikiszowiec mining settlement, located in the southern part of Katowice, constitutes a unique and fully preserved example of a company town (patronage housing estate). This residential complex, designed for workers of the Wieczorek coal mine, is included in the Silesian Voivodeship’s Route of Industrial Heritage.

The strong functional link between the Nikiszowiec and Wieczorek mines became a source of serious challenges in the early 1990s. As employment in the mines declined, unemployment increased, while the financial crisis of the Polish coal sector led to a radical reduction in support from mining companies for social and cultural activities. This resulted in social instability in many mining settlements, including Nikiszowiec.

Systematic revitalisation of Nikiszowiec became possible following the adoption of the Katowice Local Revitalisation Programme for 2007–2013, which emphasised the preservation of historical and cultural heritage alongside the regeneration of degraded urban areas [59]. A key assumption of the programme was the rebuilding of social ties through support for the activities of various stakeholders and civil society organisations [60,61].

Today, Nikiszowiec is regarded as a showcase of Katowice and the Silesian region. Social revitalisation has been accompanied by economic regeneration, and Nikiszowiec is also expected to become a centre of innovation. The Katowice Gaming and Technology Hub is a strategic project for the region’s economic transformation, a new investment located on the former site of the Wieczorek coal mine. Within the scope of the project, former mining facilities will be adapted to modern spaces for technology-oriented enterprises, with the objective of attracting innovative firms from the creative and high-tech industries [62].

Figure 5 illustrates the ongoing transformation of the former Wieczorek Mine, one of Upper Silesia’s oldest and most important mines, into the Katowice Gaming and Technology Hub, combining the revitalization and preservation of mining heritage aimed at delivering a sustainable redevelopment of post-mining areas for regional stabilisation [63].

POLAND — WIECZOREK MINE, KATOWICE



Figure 5. Transformation pathway of the Wieczorek Mine site in Katowice, Poland: from coal mining to a heritage-led gaming and technology hub [63].

3.3. Czechia: Moravian–Silesian Region

Czechia has adopted a comparatively clear and decisive coal phase-out strategy for a complete exit by 2033, which was approved by the government in 2022. The country closed its last hard coal mine on 31 January 2026, while major energy companies such as ČEZ are preparing to shut down remaining lignite operations around 2033 [12,13].

Figure 6 summarises the long-term evolution of coal production, mining employment, regional unemployment and selected structural milestones in the Moravian–Silesian Region between 1993 and 2025. The figure illustrates that the Czech transition was not a continuous

process but evolved through two distinct transformation phases separated by a period of relative stabilisation. It also highlights the close relationship between declining coal production, labour-market development and the timing of major industrial investments and policy interventions.

Transition Governance and Strategic Planning: Transition of the hard coal sector in Czechia took place in two main phases. The first phase began after 1993 and focused primarily on the closure of mines located in the Ostrava part of the coal basin of Ostrava–Karviná. Mining conditions in this area were significantly less favourable than in the Karviná part with regard to the higher extraction costs and lower labour productivity, as the coal seams were thinner and more steeply inclined. The state, the majority owner at the time, made a political decision to close these mines rapidly, driven by their economic non-viability and the need for broader economic restructuring. The scale and speed of the closures had immediate consequences on the labour-market, with unemployment in the Moravian–Silesian Region rising to approximately 14%, shaping the region’s social and economic structure. Since the closures were carried out without a comprehensive institutional or policy framework for regional transition, they resulted in a sudden loss of employment, delays in land rehabilitation, and long-term structural weakening of the regional economy [64].

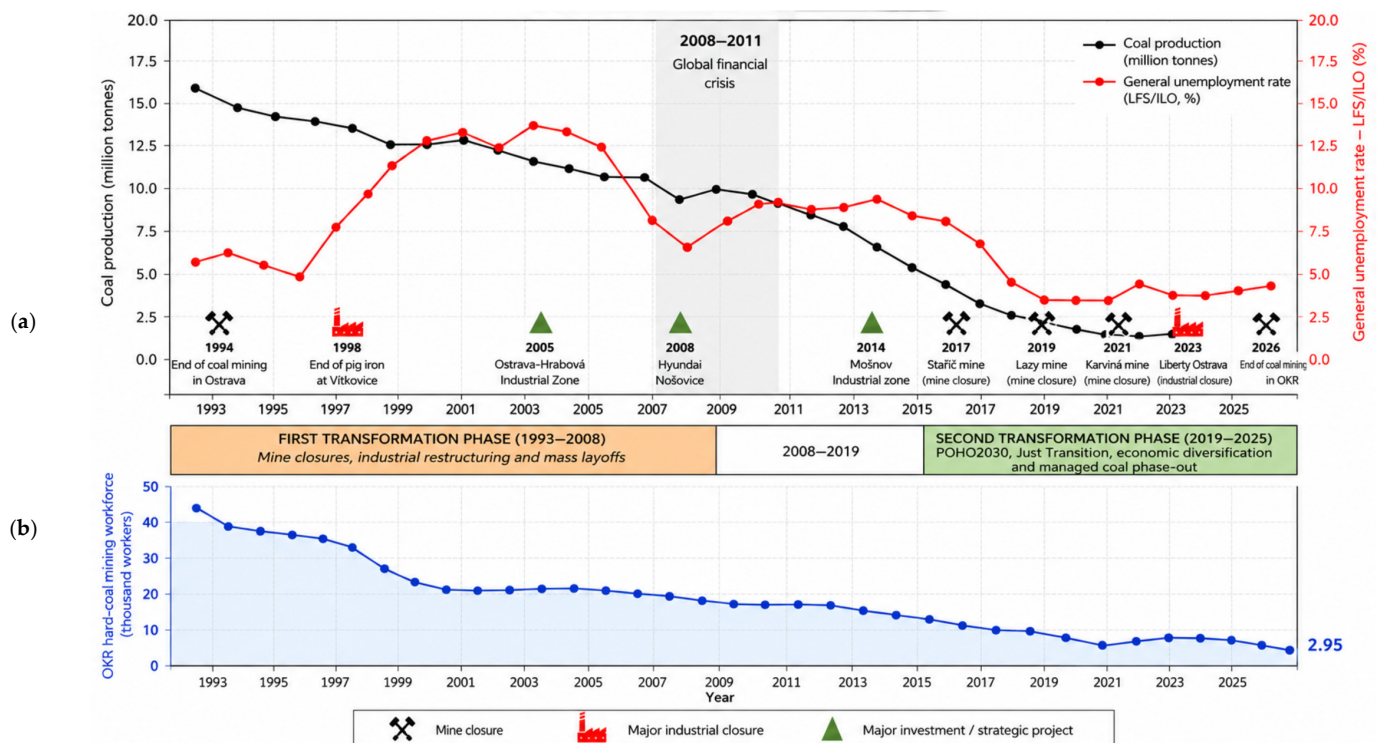


Figure 6. Changes in Czech hard coal mining between 1993 and 2025: (a) Hard coal production and unemployment [65,66]. (b) Employment rate in the Ostrava–Karviná Region [65]. Coal production includes hard coal extracted in the Ostrava–Karviná Region. Workers in coal extraction refers to the number of persons involved in coal extraction in the region, including mine contractors.

As illustrated in Figure 6, the first transformation phase was characterised by a simultaneous decline in coal production and mining employment, accompanied by a rapid increase in regional unemployment. Between 1993 and approximately 2004, coal production decreased from about 16 to 11 million tonnes, while the mining workforce was reduced from more than 40,000 to around 20,000 employees. During the same period, unemployment increased to approximately 13–14%, demonstrating that the rapid mine closures substantially outpaced the creation of alternative employment opportunities.

Afterwards, state policy gradually moved toward a more proactive approach to regional economic development. CzechInvest, established to attract foreign investment into Czechia, enabled targeted investor attraction not only in major urban centres but also in regions affected by mine closures [67]. The establishment of strategic industrial zones, particularly Ostrava–Hrabová (2005), Hyundai Nošovice (2008) and later Mošnov (2014), marked an important turning point in regional economic diversification as shown in Figure 6. These projects gradually compensated for employment losses by attracting manufacturing industries and supporting the development of regional supply chains. Hyundai alone created approximately 3500 direct jobs and around 12,000 additional jobs among suppliers [68]. The Nošovice case became a precedent for later transition strategies and demonstrated the ability of strategically managed investments to stabilise the economy in post-mining regions.

The period between approximately 2008 and 2019 represented a transitional stage rather than a distinct transformation phase. Coal production and mining employment continued to decline gradually, yet regional unemployment remained relatively stable or even decreased. This development indicates that previous industrial investments, improving macroeconomic conditions and gradual economic diversification partially compensated for the contraction of the mining sector even before the implementation of the Just Transition framework.

The ongoing second phase of transition, associated with the gradual closure of mines in the Karviná part after 2019, took place within a far more coordinated institutional setting. The national coal commission established a framework for decision-making, while both national and regional authorities adopted transformation plans financed by the EU Just Transition Fund [69]. Although the unemployment rate in the Moravian–Silesian Region remains above the national average, it has declined to approximately 6%, showing a more coordinated and mitigated transition process [70].

Unlike the first restructuring period, the closure of the remaining mines after 2019 (Staříč, Lazy, Karviná and finally ČSM) was not accompanied by a significant increase in unemployment, despite the rapid decline in coal production as seen in Figure 6. This demonstrates substantially higher resilience of the regional labour market and reflects the effects of coordinated transition planning, active labour-market policies and targeted investments financed through the Just Transition Mechanism and the POHO2030 strategy [69,71].

The current Strategic Just Transition projects focus mainly on new energy and environmental research infrastructure in Ostrava, the rehabilitation of post-mining land for renewable energy deployment, and the development of technology and innovation parks. They demonstrate that investments have been integrated within a comprehensive socio-economic framework that combines economic diversification, land restoration, and social stability [72–74].

Overall, Figure 6 demonstrates a fundamental shift in the character of regional transformation. While the first phase was largely a reactive response to the economic collapse of uncompetitive mining operations, the second phase represents a strategically managed transition based on coordinated governance, economic diversification, innovation support and planned redevelopment of post-mining areas.

Social Acceptance, Labour Transition, and Environmental Rehabilitation: Social acceptance of the coal phase-out has differed significantly between the two transition periods. The rapid closure of the Ostrava mines after 1993 was perceived as sudden and unfair. The lack of alternative jobs, slow remediation processes, and delays in regeneration and redevelopment of former mining areas increased public frustration and led to long-term distrust of transition policies.

By contrast, mine closures in the Karviná part after 2019 took place in a more structured and predictable manner. This process, better communicated and supported by visible development projects, has strengthened social acceptance. Measures such as retraining programmes, labour mobility support, incentives for new investors, and the redevelopment of brownfield sites have mitigated the decline of mining [75]. Despite these efforts, some concerns remain, particularly regarding the quality and long-term security of new jobs.

Environmental rehabilitation is now handled more systematically than during the first transition phase. Current measures include soil remediation, regular contamination monitoring, and the transformation of former mining land into areas used for economic activities, renewable energy, and public purposes [76].

Innovation and Future-Oriented Development: The Czech agenda for innovation focuses on economic diversification, deployment of renewable energy systems on reclaimed mining land, development of modern industrial parks, and measures to strengthen research and educational institutions, since innovation plays a growing role in the current coal transition strategy. Specific examples include photovoltaic projects built on former mining sites, new projects related to hydrogen technologies, and efforts to better integrate energy systems, industry, and research [77,78].

Just like in Germany, universities and research institutions are becoming increasingly important for regional development, although their role is smaller in scale. Research on soil rehabilitation and environmental restoration, as well as the establishment of new technology parks combined with investment in innovation help to create more sustainable long-term development paths for post-mining regions [79,80].

Overall, the comparison of the two restructuring phases suggests a process of institutional learning: while the first phase was predominantly reactive and accompanied by severe labour-market disruption, the later phase has taken place in a more diversified regional economy and within a substantially more developed governance and strategic planning framework.

Case Study “Dolní oblast Vítkovice and Karolina—transforming a post-mining territory into a modern cultural-innovation centre”: Dolní oblast Vítkovice (DOV) and the neighbouring Karolina site are the most famous and internationally recognised examples of post-mining transformation in the Moravian–Silesian Region. The Karolina site, a former coal mine and coking plant complex, underwent comprehensive remediation, including soil decontamination and land rehabilitation. Following this, the area was redeveloped into a modern district which includes a shopping mall and cultural centre, office buildings, and residential areas [81]. This redevelopment has effectively created a new city centre for Ostrava and represents a model transition from a contaminated mining site to an attractive and lively urban area. Figure 7 presents the transformation of the former Karolina industrial complex from a mining and heavy-industrial site into a mixed-use urban district.

The transformation of the DOV focused mainly on preserving its industrial character. Large parts of the former industrial infrastructure were cleaned and preserved for museum purposes in order to protect the industrial heritage of the region. Some structures were sensitively adapted for new uses, most famously the former gas holder, which was converted into the multifunctional cultural venue Gong. The former Hlubina mine area was redeveloped into a complex of educational, cultural, and creative spaces, including the World of Technology science centre, museum exhibitions, and creative incubators [82].

Today, the two areas are physically and functionally connected and form a unique urban space that connects historic industrial buildings to new development. The sites are well integrated into the city’s transport network, are easy to access and host a wide range of activities in the areas of culture, education, services, leisure, and creative industries. Major events that attract large numbers of visitors include the Colours of Ostrava, and Beats for

Love, as well as concerts in the Gong venue, cross-country skiing sprints, cyclocross races, beach volleyball tournaments and other urban sports events.

CZECHIA — KAROLINA SITE, OSTRAVA

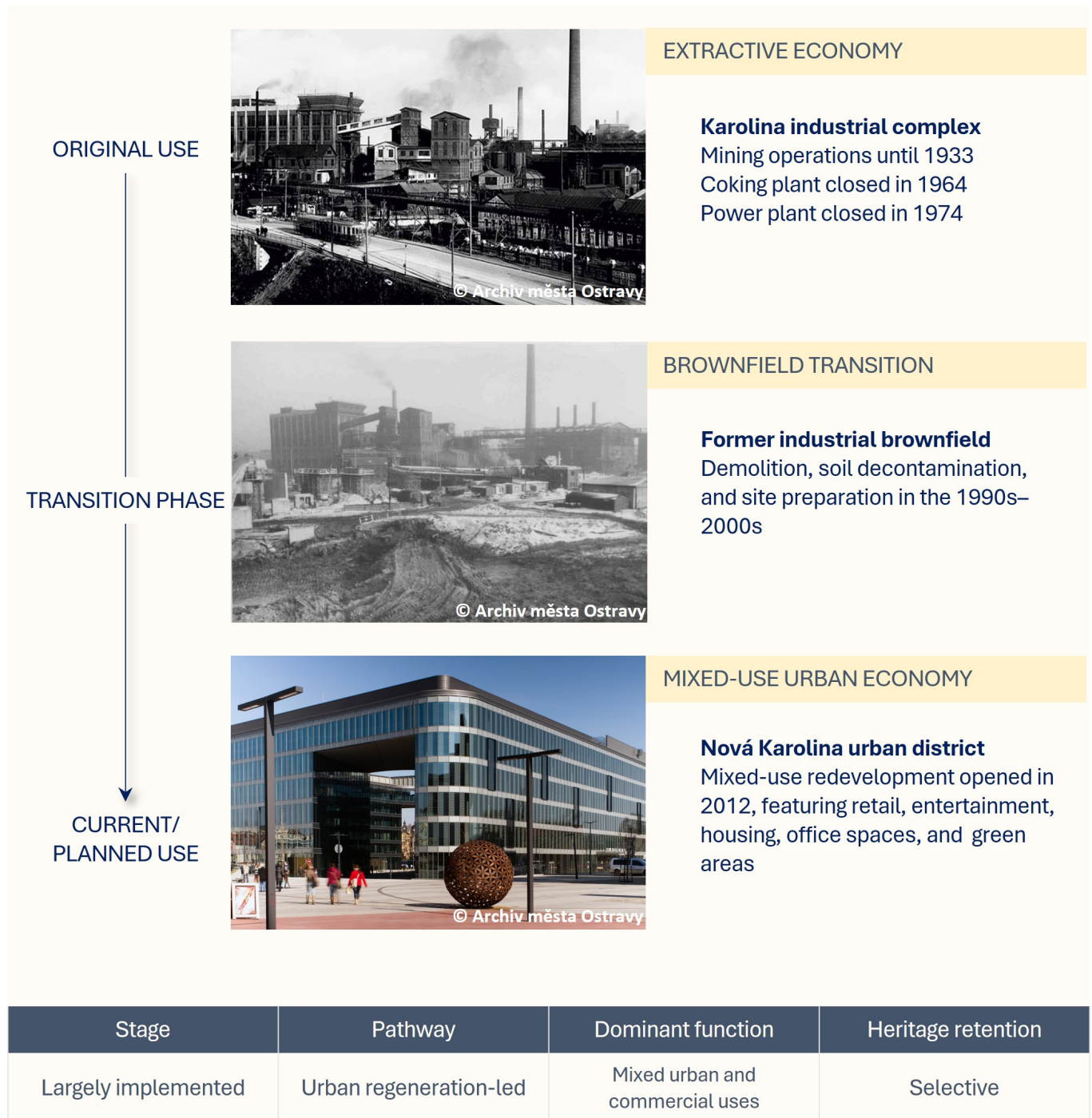


Figure 7. Transformation pathway of the Karolina site in Ostrava, Czechia: from an industrial brownfield to a mixed-use urban district [81].

This long-term transformation is currently adopting another layer through the EU Just Transition Fund. One example is the Project MUSEum+, which strengthens cultural, educational, and community functions within DOV [83]. Furthermore, the project integrates green transition elements, including energy-efficient retrofitting of heritage buildings,

climate-adaptation measures in public spaces, nature-based solutions, support for biodiversity, and environmental education.

Both Dolní oblast Vítkovice and Karolina represent a comprehensive model for coal transition in the Moravian–Silesian Region. Their developments reflect a path from coal decline and remediation through cultural and economic revitalisation to the integration of innovation, education and ecological restoration, now supported by the Just Transition Fund. This case illustrates that post-mining regions cannot simply “repair the damage”, instead, they may turn their industrial heritage into a powerful driver for regional identity, social revitalisation and climate-oriented development.

3.4. Cross-Case Comparison

The comparative assessment reveals distinct transition pathways across the three analysed coal regions despite their operation within the common climate, cohesion and just-transition policy framework of the European Union. Following the analytical workflow presented in Figure 1, the evidence from the three regional cases was compared across the six common dimensions. Table 1 presents the resulting cross-case synthesis by identifying the main regional contrasts and their comparative interpretation. The table does not repeat the individual case descriptions presented in Sections 3.1–3.3 and does not constitute a numerical assessment or ranking of the regions.

Table 1. Cross-case comparison of coal-region transition pathways across the six analytical dimensions.

Analytical Dimension	Main Cross-Regional Contrast	Comparative Interpretation
Phase-out context	Long market-driven decline; extended planned exit; disruptive restructuring followed by a planned phase	Formal phase-out dates alone do not measure transition progress; coal mining and coal-fired power generation phase-outs must be distinguished.
Governance capacity	Dense and established coordination; fragmented multi-level implementation; shift from reactive to coordinated governance	Institutional capacity differs among regions; coordination develops over time and depends on institutional continuity and implementation resources.
Social measures	Negotiated workforce adjustment; long-term social protection; retraining and investor-led employment	Pre-existing economic diversification and labour-market conditions strongly influence the social impact of closure. Unemployment trends alone cannot measure a just transition, as job quality, worker participation, and localised impacts matter equally.
Economic measures	Long-term knowledge-based diversification; uneven industrial and green diversification; strategic investment followed by innovation-oriented development	Diversification pathways depend on inherited capabilities, skills, institutions, and investment capacity.
Spatial measures	Advanced innovation-oriented redevelopment; ongoing heritage and technology reuse; mature mixed-use and cultural regeneration	Flagship projects illustrate possible pathways but are not representative measures of regional transition performance. No single optimal model of post-mining reuse exists, as effective redevelopment reflects local assets and broader regional strategies.
Persistent challenges	Socio-spatial inequalities and job-quality gaps; coal dependence and governance fragmentation; employment durability and job-quality concerns	None of the three transitions is complete or can be ranked as an unqualified success.

The first comparative finding is that formal phase-out dates alone provide an insufficient basis for assessing regional transition progress. The three regions entered coal transition under substantially different starting conditions. The Ruhr Area experienced several decades of market-driven industrial contraction before the formal end of domestic hard coal extraction. Upper Silesia remains within an extended phase-out process in which coal continues to influence regional employment, domestic energy supply, and energy-security considerations. The Moravian–Silesian Region combines the legacy of disruptive restructuring during the 1990s with a more planned recent phase. Consequently, the dates associated with mine closure, lignite phase-out, and the end of coal-fired power generation refer to different processes and cannot be interpreted as a simple sequence from slower to faster or from less to more successful transition.

The comparison also shows that governance capacity is not a fixed national characteristic but a structure that develops over time. The Ruhr’s relatively dense coordination among governments, municipalities, industry, trade unions, and regional institutions emerged progressively during a long restructuring process and did not guide the transition from its beginning. Upper Silesia has developed numerous national and regional strategies, social agreements, and funding instruments, but their implementation remains distributed across institutions and policy areas with uneven horizontal coordination. In the Moravian–Silesian Region, the contrast between the reactive restructuring of the 1990s and the more coordinated recent phase illustrates how governance arrangements can change within the same regional context. The relevant difference is therefore not simply whether transition institutions exist, but whether they provide continuity, clearly distributed responsibilities, and sufficient implementation capacity.

A third finding concerns the relationship between social protection and economic diversification. All three regions have used combinations of early retirement, financial compensation, retraining, mobility support, social dialogue, and alternative employment creation. However, the existence of these measures does not by itself demonstrate a just or successful transition. Regional unemployment trends may conceal differences in job quality, wages, employment security, worker participation, and the concentration of negative effects in particular municipalities. Similarly, the three regions have pursued different diversification pathways: the Ruhr developed a broad education-, research-, service-, and technology-based economy over several decades; Upper Silesia combines established industrial diversification with emerging green and technology-oriented initiatives; and the Moravian–Silesian Region initially relied strongly on strategic industrial investment before placing greater emphasis on research and innovation. These differences indicate that diversification pathways depend on inherited capabilities, skills, institutions, and investment capacity rather than following a single transferable model.

Post-mining land and infrastructure reuse constitutes the clearest shared feature across the cases. Each region increasingly treats former industrial sites and heritage assets as resources for new economic, cultural, environmental, educational, or energy-related functions. Nevertheless, the illustrative projects differ substantially in their historical trajectories, intended functions, and implementation maturity. MARK 51°7 represents a largely implemented transformation from mining through automobile manufacturing to an innovation-oriented district. The Wiczorek redevelopment combines heritage preservation with a technology project whose main outcomes remain under development. Karolina and Dolní oblast Vítkovice represent comparatively mature but functionally different forms of mixed-use and cultural regeneration. These projects demonstrate the range of possible reuse pathways, but they cannot be treated as representative measures of overall regional transition performance.

Overall, the cross-case synthesis does not support a linear ranking in which one region represents success and another failure. The Ruhr Area demonstrates comparatively strong institutional coordination and extensive redevelopment while continuing to face socio-spatial inequalities and job-quality gaps. Upper Silesia combines extensive social protection and emerging diversification with continuing coal dependence, coordination challenges, and investment uncertainty. The Moravian–Silesian Region demonstrates increased capacity to manage recent closures while still facing questions concerning the quality and durability of new employment and innovation-led development. Across the three cases, clearer policy signals, sustained institutional coordination, long-term investment, and the integration of social, economic, and spatial measures are associated with more stable transition patterns. However, the feasibility and transferability of these arrangements remain conditioned by each region’s historical trajectory, economic structure, energy-security context, institutional capacity, and available financial resources.

4. Discussions

The comparative cross-case synthesis indicates that coal-region transformation is shaped by the interaction of historical sequencing, governance capacity, labour-market arrangements, economic diversification, territorial redevelopment, and national energy-system constraints. No single dimension is sufficient to explain the differences observed among the Ruhr Area, Upper Silesia, and the Moravian–Silesian Region, and the evidence does not support a causal ranking or linear hierarchy of the three pathways. Instead, similar decarbonisation and restructuring pressures are mediated by inherited regional conditions and by the institutional capacity to connect social, economic, and spatial measures over time. This interpretation is consistent with just-transition research, which conceptualises transition as both a distributional and procedural challenge [6–8], and with regional path-development perspectives that emphasise the influence of inherited assets, institutions, and capabilities on shaping new development trajectories [9,10,16].

Historical sequencing represents a fundamental point of comparison. Restructuring in the Ruhr Area began during the coal crisis of the late 1950s, decades before contemporary European climate-policy frameworks emerged. This extended timeline allowed institutions, higher education infrastructure (such as Ruhr University Bochum), and alternative service and technology sectors to accumulate gradually. Conversely, Upper Silesia underwent major industrial restructuring within the broader post-socialist economic transformation after 1989, and it remains closely tied to active coal production and to the political and social consequences of future closures. Meanwhile, the Moravian–Silesian Region combines the legacy of abrupt restructuring after the early 1990s with a more coordinated recent phase. These differences suggest that the apparent maturity of a transition cannot be separated from when restructuring began or from the capabilities available at that time. In line with the literature on old industrial regions and path development [9,10,16], the comparison points to a process of cumulative adaptation rather than a uniform sequence that every coal region can reproduce.

Governance capacity further conditions how policy instruments are combined. The Ruhr Area benefits from long-established corporatist coordination and social partnership involving federal and state governments, trade unions, industry, and regional bodies [2]. In Upper Silesia, negotiated agreements with explicit phase-out timelines and extensive social protection foster broad regional consensus, though implementation operates through dispersed multi-level governance arrangements [54]. The Czech case suggests institutional learning between an initially reactive restructuring phase and the more coordinated use of contemporary EU and national instruments [69]. This does not mean that coordination automatically produces a just outcome. Rather, it makes it more feasible to align

closure decisions, labour support, investment, and land redevelopment across levels of government. The finding supports multi-level governance perspectives while reinforcing the just-transition literature's emphasis on participation, distribution, and institutional inclusion [1,6–8,26,27].

The cross-case evidence highlights why social protection and economic diversification should be assessed together. Income support, early-retirement arrangements, and negotiated adjustment can reduce immediate disruption, but they do not by themselves establish durable regional employment pathways. Conversely, investment and innovation policies cannot be treated as socially successful solely because they generate activity or jobs. Across all three regions, persistent challenges remain regarding job quality, wage parity, skills matching, and socio-spatial inequalities between former industrial cores and expanding urban centres. A place-sensitive interpretation of just transition requires simultaneous attention to protection during closure and to the durability, accessibility, and spatial distribution of replacement jobs. This helps explain why the same broad categories of EU-supported instruments can produce different regional implications [6–9,26,27].

National energy-system conditions are an additional constraint on regional transition. In Poland, the continued reliance on domestic coal cannot be interpreted only as delayed regional governance or institutional complexity. It is also linked to the composition of the national energy mix, the pace at which alternative capacity can be built, and concerns over import dependence, affordability, and security of supply that became more salient after 2022 [1,13,40–42]. Clear and credible phase-out signals can support regional planning and investment, but their feasibility and effects depend on these wider conditions. This distinction is important because it prevents the regional comparison from attributing national energy-policy choices to regional institutions alone and avoids treating different timelines as a simple measure of transition performance.

Finally, the transformation of post-mining land and infrastructure illustrates how inherited assets can support, but do not guarantee, new regional pathways. The reviewed projects range from established innovation, cultural, and environmental reuse in the Ruhr Area to heritage-led and emerging technology-oriented initiatives in Upper Silesia and cultural and mixed-use regeneration in the Moravian–Silesian Region [30–36,57–63,81–83]. These examples are illustrative rather than representative measures of regional performance, and their different stages of development limit direct comparison. Rather than treating post-mining infrastructure merely as environmental liabilities or land-reclamation costs, these integrated models demonstrate how industrial heritage can serve as a spatial and cultural foundation for redevelopment under supportive institutional conditions. The transferable lesson is therefore not a particular flagship project or a presumed “Ruhr model”, but the need to begin planning before closure, preserve institutional continuity, connect worker support with economic diversification, and integrate land reuse into a long-term regional strategy. Because the Ruhr pathway depended on decades of public investment and accumulated institutional capacity, other regions may adapt these principles but cannot be expected to reproduce its timing, scale, or outcomes. This is the central contribution of the comparison: transition instruments become meaningful only in relation to the place-specific conditions and governance capacities through which they are implemented.

5. Conclusions and Policy Implications

This study compared the transition pathways of the Ruhr Area, Upper Silesia, and the Moravian–Silesian Region within the shared climate and just-transition policy context of the European Union. The cross-case synthesis shows that formal coal phase-out dates alone provide an incomplete basis for understanding regional transformation. The differences observed across the cases are better interpreted in relation to their historical

restructuring trajectories, governance capacities, national energy contexts, degree of prior economic diversification, labour-transition arrangements, and approaches to post-mining land and infrastructure reuse. The three regions should therefore be understood as distinct, context-dependent transition pathways rather than positions on a linear ranking of transition performance.

Several policy implications emerge from the cross-case comparison. First, transition planning should begin before the final closure of mines and connect phase-out decisions with economic diversification, skills development, employment support, and territorial redevelopment. Second, multi-level coordination among national, regional, and local authorities, industry, trade unions, and other regional actors is essential to link these policy areas and maintain institutional continuity over the long term. Third, labour-market transition policies should consider the quality, stability, wage parity, and accessibility of replacement jobs, rather than focusing only on the number of jobs created. Finally, post-mining land, infrastructure, and industrial heritage should be systematically integrated into broader regional development strategies as spatial and cultural assets, rather than treated merely as environmental liabilities or isolated reclamation tasks.

The findings underline the necessity for place-sensitive European and national transition policies. Common climate objectives and financial mechanisms operate across regions with different levels of coal dependency, institutional capacity, fiscal resources, and exposure to energy-security constraints. Policy frameworks should therefore provide predictable long-term direction while retaining sufficient flexibility to respond to these differences. In particular, while the Ruhr Area's historical trajectory offers relevant principles concerning early preparation, corporatist coordination, sustained social dialogue, and asset reuse, it should not be treated as a universally transferable model. Its transformation has depended on several decades of restructuring, substantial public investment, and institutional capacities that may not be available to all coal-dependent regions.

This study is subject to several limitations. It is based on a qualitative, document-based comparison of three Central European coal regions and does not seek to establish causal relationships, produce a quantitative ranking, or generate statistically generalisable conclusions. Documentary sources vary in scope and level of detail, while the available regional statistics are not fully harmonised in terms of indicators, territorial definitions, and historical timeframes. Some dimensions, particularly social acceptance, can therefore be assessed only indirectly through documented institutional processes and secondary evidence. Future research could expand upon these findings by employing harmonised longitudinal datasets, structured stakeholder interviews, or a broader comparative sample encompassing non-EU coal regions.

Overall, the comparison indicates that coal-region transformation does not end with mine closure. It is a long-term process in which social, economic, institutional, and territorial changes develop at different speeds and under different contextual constraints. Effective transition policy must consequently extend beyond managing the immediate consequences of closure and support the long-term capacity of regions to develop viable pathways beyond coal.

Author Contributions: Conceptualization, T.D., H.F., S.J.-S. and J.Š.; methodology, T.D., H.F., S.J.-S. and J.Š.; validation, T.D. and H.F.; investigation, T.D., H.F., S.J.-S. and J.Š.; writing—original draft preparation, T.D., S.J.-S. and J.Š.; writing—review and editing, T.D., H.F., S.J.-S. and J.Š.; visualization, T.D., H.F., S.J.-S. and J.Š.; project administration, S.J.-S.; funding acquisition, S.J.-S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Research Fund for Coal and Steel (RFCS), under grant agreement number 101216335.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data supporting the findings of this study are derived from publicly available historical and statistical sources, as cited in the article. The data used in the analyses and figures are presented within the article. Additional information is available from the corresponding author upon reasonable request.

Acknowledgments: We acknowledge all partners of the RAISING Project for their valuable contribution to our ongoing research. Furthermore, the authors thank COST Action REMINDNET (CA22138), supported by COST (European Cooperation in Science and Technology).

Conflicts of Interest: The authors declare no conflicts of interest.

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