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PERSPECTIVE

Just energy transition: navigating Poland's transition away from coal mining

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Abstract

This perspective paper analyses Poland's transition from coal mining, focusing on Upper Silesia—home to the EU's largest coal mining workforce, with 78 500 direct mining jobs and an additional 21 000 indirect jobs at stake. Drawing upon original data analysis and existing literature, the paper examines the complex relationship between the coal phase-out and demographic decline at the powiat (county) level. While projected population decline could partially offset job losses from mine closures, the effects vary dramatically across powiats—from potential unemployment reaching 20.27% in Bieruńsko-Lędziński powiat to projected labor shortages in areas like Bytom and Zabrze. Despite a significant decrease in job opportunities in coal mining, averaging a 7.85% decline across affected powiats, there is a considerable likelihood that other industries will encounter labor scarcities. Second, the impact extends beyond direct mining employment—contractors and service providers are particularly vulnerable, with 70% of the 1054 identified contracting companies dependent on a single mine. Third, retraining faces specific barriers: miners strongly resist relocation, are reluctant to accept wage reductions and show limited interest in solar and wind energy sectors, suggesting energy efficiency, automotive, and ICT sectors as better alternatives. The paper demonstrates that successful transitions require understanding local contexts, from workers' skill transferability to transportation infrastructure to fiscal capacity. These insights from Silesia offer valuable lessons for both developed economies managing industrial transitions and emerging economies seeking to balance economic development with decarbonization.

1. Introduction

Ninety-seven percent of the European Union's hard coal is produced in Poland, predominantly in the Southwestern Upper Silesian Coal Basin that spans the center of the region Silesia and extends into the neighboring Małopolskie region (Alves Dias *et al* 2018, Bijańska and Wodarski 2024). As the EU has committed to reaching net zero emissions by 2050, Poland has just over two decades to decarbonize and phase out coal entirely. This places Silesia, home to the EU's largest coal mining workforce, at the heart of Europe's green transition (Alves Dias *et al* 2018).

Beyond its significance for European decarbonization efforts, Silesia represents an important case study for understanding coal transitions globally. With approximately 78 500 direct coal workers and an additional 21 000 indirectly employed in 2019 (Sokołowski *et al* 2022, Frankowski *et al* 2023), Silesia's coal workforce is significantly larger than the Appalachian coal region in the US (27 632 total coal jobs in 2023; Garside 2024) and is more comparable to the coal workforce in South Africa (approximately 91 000 in 2022; Statista Research Department 2024b). Notably, Poland is already undergoing its second major coal phase-out, with the first occurring after the collapse of the Soviet Union. While significant, Poland's current coal mining workforce is considerably smaller than those of other post-Soviet states—Kazakhstan employs 274 000

workers in its mining and quarrying sector (CIEC 2018), while Russia employs 140 600 coal workers (Statista Research Department 2024a).

Silesia stands out for its combination of a highly-industrialized economy with strong manufacturing sectors, a high degree of urbanization and population density, and relatively low fiscal dependency on coal revenues. This makes it an instructive case study for both developed economies managing industrial transitions and emerging economies seeking to balance economic development with decarbonization. The region's experience with managing simultaneous challenges—maintaining industrial competitiveness, addressing demographic decline, and preserving social cohesion—is particularly relevant for coal regions worldwide that must navigate multiple transitions simultaneously.

Looking at Poland specifically, while the country has achieved the fastest decarbonization rate of its economy worldwide, measured by the ratio of CO_2 emissions to GDP between 1990 and 2022, the country has made limited progress in reducing its dependence on coal for domestic energy consumption (Rentier *et al* 2019, Pielke 2024). The country faces the massive undertaking of transitioning most of its power grid to climate-friendly sources. On the energy demand side, Poland must replace 82% of its electricity generation, which depends on coal, with clean electricity sources (IEA 2023). Coal accounts for 58% of Poland's energy-related greenhouse gas emissions, ranking Poland and Australia as having the highest CO2 intensity of their energy supply among International Energy Agency members (IEA 2022). Aside from the financially unviable option of installing carbon capture and storage on coal plants, the country has no option but to phase out coal on its pathway to reach net zero emissions (Rentier *et al* 2019).

Phasing out coal will directly impact the livelihoods of workers in coal-related sectors. Nearly 100 000 workers are either directly or indirectly dependent on coal mining in the Upper Silesian Basin alone (authors' calculations based on Sokołowski *et al* 2022, Frankowski *et al* 2023). This represents 3.54% of Silesia's 2.8 million working-age population in 2019 (ibid). In the powiats (counties) most dependent on coal, up to 20.27% of the workforce relies directly or indirectly on coal mining for jobs (ibid). Historically, the Silesian region was a magnet for labor due to its coal mining industry, with at least one active mine operating in seven of its powiats over the past three decades (Sokołowski *et al* 2022). Beyond its economic significance, coal mining has deeply permeated Silesia's cultural fabric, reflected in local folk traditions and the elevated status of miners within the community. The central role of mining is ingrained in the regional identity of Silesia. The 'Silesian ethos' originated alongside the rise of coal mining in the 19th century, emphasizing values like discipline and respect that were pivotal for safeguarding miners' well-being (Baran *et al* 2020).

Transitioning away from coal poses a complex challenge to the region and the country, necessitating adept management. The collective memory of the tumultuous transition in the 1990s fuels concerns about potential socio-economic repercussions for the region (Brauers and Oei 2020). Simultaneously, demographic projections for the region are devastating, foreseeing a stark decline in the working-age population in the coming years. This creates a twofold challenge: (1) averting unemployment as the coal industry winds down while also (2) addressing labor shortages amidst demographic decline.

This timing masks a more complex reality. Even with natural attrition given that 40% of the workers are above the age of 50, thousands of miners will still be in the labor force by 2030 and 2040—far before their retirement age (Christiaensen *et al* 2022). Moreover, the loss of well-paying coal jobs creates ripple effects beyond direct workers. It affects the next generation's job prospects, potentially accelerating outward migration and further deepening the region's demographic challenges. The double bind of mine closures and population decline risks decreasing Silesia's attractiveness for new investments precisely when the region needs to diversify its economy. This could create a cycle: fewer job opportunities lead to more outward migration, which in turn reduces the region's ability to attract employers, resulting in even fewer jobs. At the same time, other industries in the region may face labor shortages due to demographic decline, creating a paradoxical situation where unemployment and labor scarcity coexist. Understanding how to manage this relationship between coal phase-out and demographic decline is crucial for the region's future.

Despite the scale and scope of the challenge, literature only recently started discussing the implications of different coal phase-out scenarios for Silesia. Often overlooked are the distinct challenges different powiats face in the region as they transition. Furthermore, little is known about the costs of a phase-out and how policies can approach restructuring the labor market while avoiding backlash from miners and preventing labor shortages in other industries. To illuminate the path forward, this article first examines how current literature discusses the coal phase-out and analyzes the specific economic and demographic characteristics of the Silesian mining region. After assessing the magnitude of the transition, the paper explores the challenges powiats face and how these can be addressed by considering the different stakeholders involved. This aims to stimulate further research on Silesia's coal phase-out and its implications for the labor market and industry. If managed effectively, the transition can mitigate community concerns, open new economic opportunities for the region, and establish Silesia as a pillar of Europe's decarbonized economy.

2. Past coal decline in Poland

While a coal phase-out by 2050 may seem daunting, it is not the first transformation of Poland's mining sector. Employment in Polish coal mining dropped 75% from 388 000 jobs in 1990 to 98 000 in 2015, with most layoffs occurring before 2002 (Szpor and Ziółkowska 2018). This massive downsizing proceeded amidst Poland's full-scale economic and political transition from a centrally planned economy to an open capitalist model. As such, the mining sector changes were overshadowed by the sweeping systemic reforms occurring in the country during the 1990s.

The 1998 Mining Social Package, the most ambitious program at that time, intended to restructure the sector and dramatically reduced mining employment by 102 600 workers, with 67 000 workers leaving voluntarily and the rest retiring regularly (Śniegocki *et al* 2022). One of the central provisions of the Package was offering a one-time welfare allowance to encourage voluntary retirement. 29 700 miners took the one-time allowance and left the labor market to retire early (Paszcza 2010). Only 419 miners opted for an increased one-time allowance that included a bonus on the condition of finding a new job within two years of leaving the mine. Given the tight labor market at that time due to the economic upheaval of Poland's transition to a capitalist economy, the requirement to find a job in such a short time frame was perceived as too risky (Śniegocki *et al* 2022). Furthermore, the increased allowance was tied to requirements such as considering job offers and participating in retraining, making the unconditional one-time financial benefit more attractive (ibid.). Hence, while the one-time allowances incentivized workers to voluntarily leave the sector, it did not result in finding new employment or starting a business. Moreover, retraining options were poorly designed and insufficient, resulting in a 7.5% unemployment spike in Silesia between 1999 and 2003 (ibid.). Hence, the support measures did not stop coal mining workers from permanently exiting the labor market in large numbers. More elaborate transition policies, which would have focused not only on reducing the labor force but also on creating new employment opportunities for workers who left the mines, could have better cushioned this drastic economic shift. However, this was complicated given the external circumstances in Poland at that time, as the whole economy was transformed to a capitalist one. Job losses were not confined to the mining sector but were a widespread phenomenon. Importantly, unlike the 1990s, when unskilled miners faced challenges securing employment amid a shrinking labor market, the green transition has distinct characteristics. The higher education levels of present-day miners, coupled with rising labor demand due to labor shortages, place miners in a better position to find new employment (Sokołowski *et al* 2022).

Despite Poland's major coal mining sector reforms in the 1990s offering potential insights into transition challenges, academic literature on coal phase-outs predominantly focuses on the United Kingdom, the United States, Germany, and, more recently, China (Diluiso *et al* 2021). Research on Poland's coal phase-out is often written in Polish and receives little international discussion. Much of the existing work on the Polish coal sector comprises reports from think tanks or international organizations like the World Bank, analyzing past policies (Śniegocki *et al* 2022) or modeling the Polish energy market (Żelisko and Kopeć 2024). Several publications describe the demographics of coal workers, specifically in Silesia (Kiewra *et al* 2019, Cichy *et al* 2021). The authors characterize the underground miners as younger than 50 years old, predominantly male with secondary education and an average of 15 year of work experience in mining (Cichy *et al* 2021). Another study, which includes a non-representative survey of miners, shows that the salary plays a crucial role in miners' future job considerations, followed by job stability (Kierwa *et al* 2019).

Recently, academic research has increasingly focused on the Polish coal phase-out. After 1990, the Polish coal industry faced pressure given its inefficient over-employment and from stricter environmental and pollution policies upon becoming an EU Member State (Brauers and Oei 2020, Bórawski *et al* 2023). Initially concentrating on economic development and transitioning to a capitalist economy post-1990, the country must now shift from its carbon-intensive growth model to a decarbonized approach (Dragan and Zdyrko 2023). As in the 1990s, the mixture of uneconomic mines and EU policies are the drivers of the impending coal phase-out (Brauers and Oei 2020). However, the embeddedness of a pro-coal coalition within the political landscape has, thus far, succeeded in sustaining mining (ibid.).

Given the acknowledgement of the need of a transition, an increasing number of papers concentrates on labor market and socioeconomic effects of the transition. A range of energy sector models explores cost-minimizing transition scenarios towards renewable energy, highlighting that, despite a decline in traditional jobs, there would be a moderate increase in new job opportunities through RES deployment (Antosiewicz *et al* 2020). Employment prospects for miners during the current transition are significantly brighter than during the first transition in the 1990s, given the higher educational level and lower labor supply today (Sokołowski *et al* 2022). However, finding new jobs in different sectors will still prove challenging, considering the high pay and job stability in mining (Baran *et al* 2020). A less discussed fact is that a large number of indirect workers will also be affected by the phase out (Frankowski *et al* 2023). Further

Figure 1. Silesia within Poland. This Silesian in Poland (+rivers) image has been obtained by the author(s) from the Wikimedia website where it was made available by TUBS under a CC BY-SA 3.0 licence. It is included within this article on that basis. It is attributed to TUBS.

gaps in the literature remain around adequately planning and supporting labor market transitions for affected coal regions, such as Silesia (figure 1), during decarbonization processes that will extend beyond coal mines to the industry and the region as a whole.

3. Silesia coal mining region

Silesia has been central to Poland's economic shifts following the collapse of communism. As the most industrialized and densely populated region in Poland with 368 persons per km^2—compared with just 120 persons for the whole country—Silesia employed over 1 million people in the industrial sector in 1990, including significant portions in mining and steel production (Baranyai and Lux 2014, Eurostat 2023, Statistics Poland 2024). Despite the closure of coal mines and factories, Silesia remains the leading Polish region in gross value added (GVA) from industry, establishing itself as one of the country's wealthiest provinces (European Commission 2020). It developed into a hub for new manufacturing industries, especially in automotive and advanced manufacturing. Silesia now is part of one of Europe's largest automotive clusters and has seen notable growth in the service sector, particularly in finance, insurance, and information-communication (Baranyai and Lux 2014, Micek *et al* 2022).

Against this backdrop, the region is poised to be part of another transition. The Polish coal phase-out is set for 2049, established by the former ruling Law and Justice party (PiS) in collaboration with trade union representatives (Ministerstwo Aktywów Państwowych 2020). This so-called Social Contract promises employment safeguards and preretirement payments, $4.1 billion in investments in clean coal technologies, and a Transformation Fund for Silesia (Śniegocki *et al* 2022). To manage the transition, Poland can leverage the EU Just Transition funds, which allocates €2.4 billion to Silesia and Western Małopolska (European Commission 2022).

Following the PiS defeat in the October 2023 elections to a three-party coalition led by Donald Tusk, the new government has explored the possibility of moving the coal phase-out date forward (Kurmayer 2024). This potential acceleration of the coal phase-out will have a distinct impact on the Upper Silesian Coal Basin labor market in the coming decades, as 99 500 direct and indirect mining jobs would be irrevocably lost.

Mining continues to play an essential role in various Silesian counties, fueled partly by the notably elevated wages offered in the mining sector. Polish miners enjoy high wage premiums, compensating for the hazardous nature of their work. Data from 2014 indicates that miners earned an average monthly salary of 1640 USD in purchasing power parity terms (6559 PLN), significantly surpassing the 727 USD (2907 PLN) monthly salary in the manufacturing sector (Witajewski-Baltvilks *et al* 2018). Silesia maintains the country's

second-highest gross disposable income per capita, trailing only behind the capital region of Warsaw (Statistics Poland 2022). Moreover, retirees in Silesia receive the most generous pensions nationwide, and the region boasts the third-lowest risk of poverty in Poland, with only 2.3% of individuals in households falling below the subsistence minimum in 2019, compared to the national average of 4.2%. In contrast, Małopolskie, Silesia's neighboring region, which also hosts two mines of the Upper Silesian coal mine basin, is home to the highest percentage of individuals below the subsistence minimum, standing at 7.5% (Statistics Poland 2022).

In the context of the coal phase-out, Silesia as Poland's first mining region still has the largest coal mining workforce in the country but faces different fiscal and labor market challenges in transitioning away from coal compared to other coal regions in the country due to its more diversified economy, higher population density, and lower fiscal dependency on the coal industry. While other coal regions' share of total revenues from coal stands at 16.45%, Silesia's share is significantly smaller with 3.31%, given that Silesia's hard coal mining is less capital-intensive than lignite mining, resulting in lower property tax revenues collected (Swoczyna and Karaczun 2023).

Since Silesia's primary challenge is its labor market rather than revenue dependence, the region's significant natural decrease in population of 5.76 persons per 1000 people annually will become a critical concern. Contributing to this natural decline, the region experiences an annual negative net internal migration of 0.8 persons per 1000 persons to other regions of Poland (Statistics Poland 2022). Although demographic decline is a shared nationwide and EU-wide trend, it is more pronounced in Silesia than in other regions and has been a long-standing issue. Between 2000 and 2017, Silesia's population shrunk by 4.4%, contrasting with the overall increase in the Polish population (European Commission 2020). Therefore, when planning the region's transition, policymakers should address Silesia's characteristics as a high-income, highly industrialized, and highly populated region facing rapid demographic decline.

4. Employment effects

The upcoming coal phase-out will have far-reaching consequences beyond mine workers, affecting both indirectly employed workers and future generations in the region who will face a diminished job market. While demographic decline in the region may partially offset the lack of jobs, incentives for leaving the region persist, potentially accelerating population loss. Even accounting for natural attrition through retirement, the mining workforce will remain substantial: of the current 78 500 miners, about 45 700 will still be working by 2030, 19 000 by 2040, and falling further to less than 7000 by 2049 (authors' calculations based on Sokołowski *et al* 2022 and Katowice Statistical Office 2023).

Beyond directly employed workers, the phase-out's impact extends to indirect jobs, particularly those provided by firms directly supplying services to the mines. Estimates for indirect job losses vary between 14 000 and 130 000 (Frankowski *et al* 2023). In Silesia alone, an estimated 20 957 employees face imminent risk of layoffs, while an additional 30 210 are classified as vulnerable (ibid). Of 1054 companies found to contract with Silesian mines, 70% demonstrated high dependency by working with just a single mine (ibid). 70% of the contracting companies were located in Upper Silesia, while 7% were in the neighboring region Małopolskie (ibid). The mines support many indirect workers, including manufacturers of underground mining infrastructure and equipment in companies like PBSz and FAMUR, and service providers like Nitroerg which handles drilling and blasting (ibid). Although most indirect workers are blue-collar employees in manufacturing and construction, white-collar workers make up 28% in the indirect workforce—a higher share than in mines themselves (Christiaensen *et al* 2022). Unlike directly employed miners, blue-collar workers in indirect employment often provide support services such as cleaning or security. Given these distinct workforce characteristics, employment programs designed for mine workers may not adequately address the needs of indirect workers, who also risk losing their retirement benefits along with their jobs during a coal phase-out. In the Bełchatów region, one-third of indirect workers will not have reached pension eligibility by 2038, when the local mine is scheduled to complete its phase-out (Kiewra 2021).

Silesia faces a dual challenge: the loss of mining workplaces and a shrinking population. The projected loss of 99 500 direct and indirect workplaces due to coal phase-out represents 3.54% of Silesia's current (2019) working-age population. Due to the projected population decline, the job loss would amount to 5.63% of the region's 2050 working population. To put these numbers in perspective: Silesia's current unemployment rate is 3.4%, and even the COVID-19 pandemic, with its significant economic disruption, only increased unemployment in Poland by one percent (OECD 2024). These substantial workplace reductions create a 'lost employment potential', particularly challenging for the younger generation seeking jobs in the region.

Powiats will experience vastly different impacts from the coal phase-out (figure 2). In 2019, mining employment ranged from less than 0.5% of the working-age population in the least affected powiat to

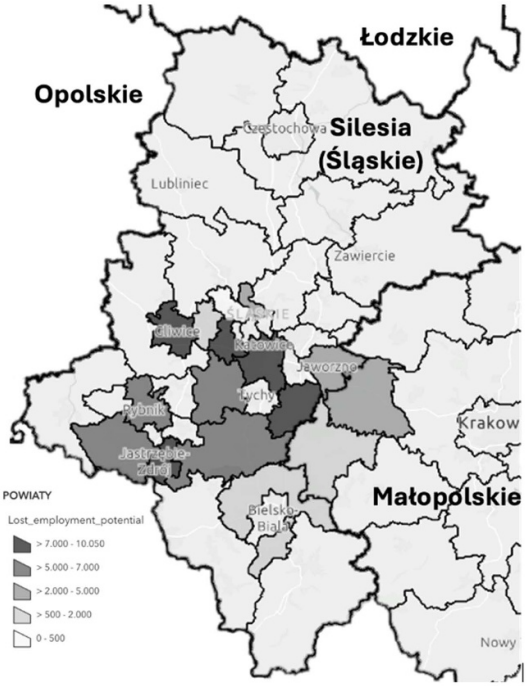

Figure 2. Lost employment potential in all affected powiats in Silesia and Małopolskie in case of a complete coal phase-out. *Source*: Sokołowski *et al* (2022), own calculation and depiction. While most mines are located in Silesia, two mines of the Upper Silesian Coal Basin are located in the Małopolskie region.

Table 1. Estimated labor shortage relative to the projected working age population. Source: Authors' calculations based on Frankowski *et al* (2023), Sokołowski *et al* (2022), and the Statistical Office of Katowice (2023). Negative numbers for net labor shortages imply that more jobs in mining will be lost than the population decreases, suggesting that the powiat will face unemployment and labor surpluses.

Powiats	Projected population decline	Estimated lost workplaces in mines	Projected net labor shortages
Mikołowski	2978	5334	−2356
Bieruńsko-Lędziński	4278	7860	−3582
Rybnicki	5865	6415	−550
Piekary Śląskie	6176	2688	3488
Bielski	7559	1992	5567
Pszczyński	8436	5310	3126
Jaworzno	10 735	2838	7897
Jastrzębie-Zdrój	11 296	10 042	1254
Chrzanowski	13 484	2540	10 944
Oświęcimski	14 332	1728	12 604
Ruda Śląska	14 845	7246	7599
Wodzisławski	15 196	6231	8965
Gliwice	16 952	7694	9258
Bytom	22 218	450	21 768
Katowice	24 734	9627	15 107
Zabrze	25 839	505	25 334

20.27% in Bieruńsko-Lędziński (own calculations, based on Katowice Statistical Office data and Sokołowski *et al* 2022).

Among the powiats, Rybnicki, Bieruńsko-Lędziński, and Mikołowski show the smallest population decline (table 1). In these three powiats, job losses from the transition will exceed the natural decline in the working-age population, likely leading to increased unemployment unless new jobs are created. Other powiats face the opposite challenge: their working-age population is declining more rapidly than workplace availability, suggesting they may face labor shortages without inward migration.

Most powiats are expected to face labor shortages rather than unemployment, presenting Silesia and Poland more broadly with a paradoxical situation. Despite an average 7.85% decline in coal mining jobs across affected powiats, demographic decline suggests that other industries will likely face labor scarcities. While this labor shortage might lead to higher wages in new industries for ex-miners, the combined impact

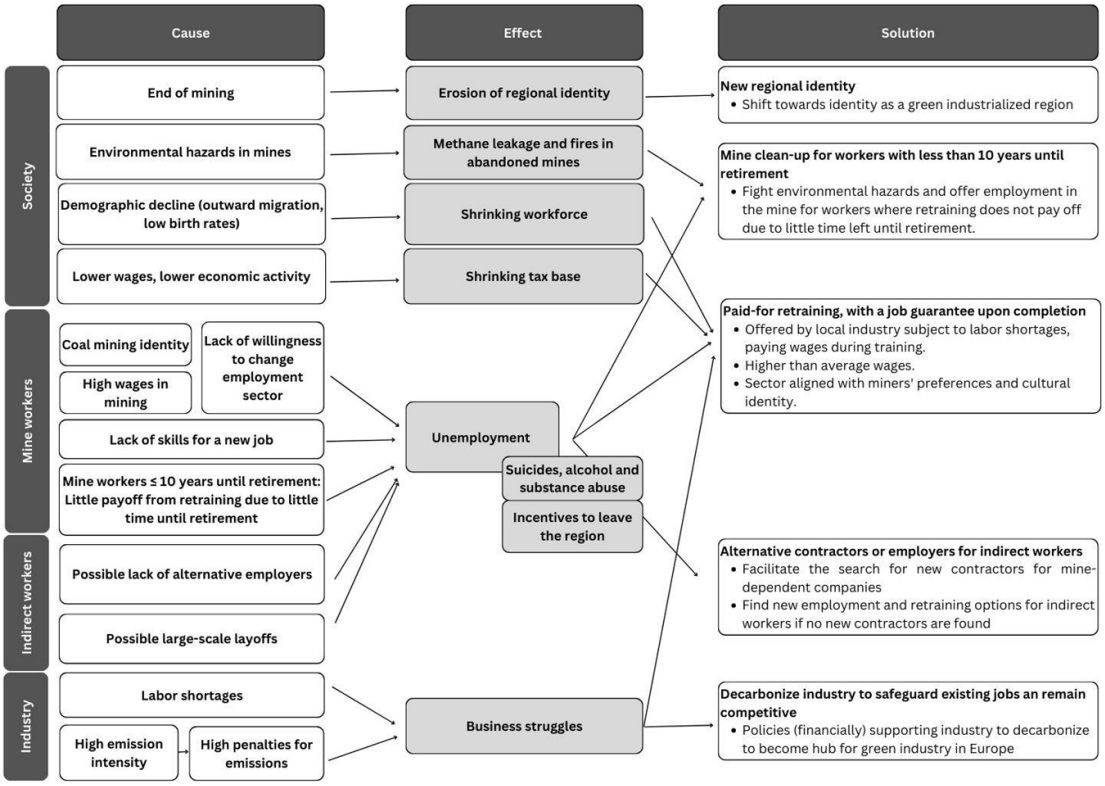

Figure 3. Overview of the ripple effects of a coal phase-out on society, direct and indirect workers, and industry in Silesia and potential solutions to address the issue. Own depiction.

of mine closures and demographic decline could decrease Silesia's overall attractiveness and accelerate outward migration. Current miners prefer to stay in the region, but job perspectives for the younger generation appear much bleaker. The traditional high-paying mining jobs for blue-collar workers—which often offer wage premia of up to 50%—are phasing out (Christiaensen *et al* 2022). This may force youth seeking higher-paying jobs or in white-collar jobs to leave the region. Evidence from Bełchatów, a region north of Silesia with a lignite mine employing nearly 9000 workers, illustrates this risk: a survey revealed that nearly half of the region's upper secondary school students plan to emigrate after completing school (Alves Diaz *et al* 2018, Bujalski 2020).

5. New perspectives

For Silesians, coal mining is not just a job; it is a regional identity deeply embedded in local customs, traditions, and ethos. Coal miners have historically enjoyed an elevated social status and are accustomed to strong unionization rather than a competitive market environment (Kowalik *et al* 2024). Crafting a positive new narrative and identity for the region is essential, while respecting its traditions and cultures, even amidst mine closures. This updated identity could be closely aligned with Silesia's industrial character while embracing green industrialization.

The recent change in government leadership under Prime Minister Donald Tusk presents an opportunity for an earlier coal phase-out and higher investment in the decarbonization and structural transformation of the region. The decision to locate the Ministry of Industry in Katowice, Silesia's capital, signals the government's commitment to the region. Regardless of political leadership, Silesia faces fiscal challenges: it must address its shrinking tax base caused by declining wages and unemployment. Silesia has the lowest per capita revenues in Poland, while maintaining the second-highest budget expenditures (Statistics Poland 2022). Without intervention, this could lead to reduced public services or increased public debt, potentially accelerating outward migration.

Given these complex dynamics, targeted interventions are needed to manage Silesia's structural transition. Based on the existing literature and best practices, several strategies warrant consideration to address both the unemployment of direct and indirect workers and the paradoxical labor shortages in other industries (figure 3).

5.1. Energy jobs

New energy sectors, particularly 'green jobs' in energy efficiency and renewable energy, offer significant employment potential. For example, a report on the Bełchatow coal region estimates that green jobs could create six times more employment than existing mining jobs in the region, if Poland leverages the EU Just Transition Territorial Plan funds (Czyżak *et al* 2020). Energy efficiency initiatives, particularly house retrofitting, present another significant opportunity. Thermal retrofitting could generate approximately 24 850 jobs in the Bełchatow coal region (Czyżak *et al* 2020), suggesting even greater potential in the larger Silesian region.

However, the solar sector presents challenges for miners seeking stable employment: manufacturing is unlikely to return from China, while installation jobs are typically temporary or require travel. This helps explain why solar and wind jobs have limited appeal among miners. Despite existing retraining programs, only ten percent of miners viewed these sectors as a viable alternative, citing concerns about the nature of the work, lower salaries, and perceptions of green industry replacing traditional jobs (Kierwa *et al* 2019). Similarly, interviews with U.S. coal miners revealed apprehension about the low pay and temporary nature of renewable energy sector jobs (Sicotte *et al* 2022).

Two additional energy sectors show promise for job creation: geothermal energy (Kurek *et al* 2021) and nuclear power expansion, which could also provide stable well-paying jobs by repurposing coal power plant sites for nuclear (Haneklaus *et al* 2023). Yet, after the construction stage, the nuclear sectors' employment impact is modest. A 1 GW nuclear plant needs just 500–700 workers to operate, and these positions require specialized training that further limits its viability as a broad solution. Still, based on international evidence, nuclear energy wages are the highest in the energy sector, 27% higher than coal (Lehmann *et al* 2021).

5.2. Employment in other industries

Silesia's high degree of industrialization and strategic location near European markets—rather than its coal resources—has attracted major industries and created job opportunities, with the region's GVA exceeding the Polish average. The region hosts automotive manufacturing, chemicals, and steel production.

While these sectors' future depends on broader EU economic conditions, their decarbonization potential varies significantly. The regional heavy industry must decarbonize to remain competitive with the EU emissions trading system. Industries relying on electricity as a direct input can transition more easily, and emissions could be more than halved by 2030 if coal is reduced to 13% of electricity generation (Czyżak and Wrona 2021b). The automotive industry shows particular promise, with miners expressing interest in this sector (Kierwa *et al* 2019), as the industry transitions to electric vehicle production. Other sectors face greater challenges—the steel industry needs green hydrogen, while the chemical manufacturing depends on oil derivatives as feedstock.

Beyond traditional industries, the growing ICT sector, attracted by Silesia's skilled workforce and lower operating costs compared to other EU locations, could create high-paying jobs, although it currently represents only 2.4% of Silesia's GVA (European Commission 2020). These diverse industries, despite their challenges, could offer crucial retraining and employment pathways for both miners and young workers. EU Just Transition funding can further enhance this potential through worker requalification programs in partnership with local industries. The key challenge lies not in attracting these industries, which are already present and expanding, but in developing effective training and retraining programs that align with their workforce needs.

The transition strategy must also include indirectly employed workers previously linked to coal mining. The primary focus should be on helping contractors identify alternative customers, both in Poland and internationally. Chambers of commerce could facilitate this matchmaking process.

5.3. Re-skilling and retraining

Finding new employment is challenging, regardless of age, and the specialized skill set of coal workers further complicates the job search. As outlined in Poland's updated draft National Energy and Climate Plan, the energy transition will substantially increase labor demand, with skills shortages potentially becoming a critical bottleneck (Ministry of Climate and Energy 2024). While Polish miners are better educated than during the first transition of the 1990s, laid-off miners face considerable skills mismatch for successful integration into the labor market (Christiaensen *et al* 2022). The job prospects vary significantly among coal workers, but the skills gap for coal jobs is more significant than for other fossil fuel jobs (Greenspon and Raimi 2024). Some miners have highly transferrable skills, such as operators of coal processing machines and conveyor belts, as well as drivers of mining hosting machines, fitters of vehicles, and transport devices (Christiaensen *et al* 2022). These workers can likely switch to similar, comparably-paid jobs in the region with minimal to no retraining (ibid). Underground miners, who constitute the largest share of coal workers,

have less transferable skills. Their closest matching profession—bricklaying—would entail a nearly 40% income drop and a significant change of tasks (ibid). While viable transition pathways exist for some coal workers, matching laid-off miners with new jobs remains challenging. Furthermore, miners show hesitance to transition to other sectors due to likely wage reductions. A survey revealed that Polish miners would rarely accept wage reductions exceeding PLN 250 (approximately 58 Euros), less than 4% of their 2018 wage (Kierwa *et al* 2019). Better prospects will require retraining and re-skilling, depending on the target profession.

Miners with less than ten years until retirement may face additional challenges due to the perception that retraining (or other educational investments) is not worth it. Workers closer to retirement might benefit from alternative non-extractive employment at mines, e.g. assisting with cleanup activities and addressing safety concerns, such as methane leaks and fire hazard in closed mines (Richardson *et al* 2021). Poland's current energy policy includes phased mine closures, allowing older miners to complete their careers in nearby mines. Currently, Silesia is the region with one of the highest levels of pollution in the EU. This has spurred the European Commission to classify environmental degradation of land as a high-priority challenge of the transition—ranking it as even more important than retraining (European Commission 2020).

For younger workers, retraining programs must align with the needs of the alternative employment sectors, as the potential loss of nearly 100 000 jobs means the next generation cannot rely on mining employment (authors' calculation based on Frankowski *et al* 2023, Sokołowski *et al* 2022, and the, Statistical Office of Katowice 2023). A UK case study highlights substantial salary cuts resulting from labor oversupply during coal phase-outs (Rud *et al* 2022).

Yet, given Poland's population decline, not all regions may face labor surplus. Instead, the primary challenge may be a mismatch between available labor skills and emerging industries' demands. Therefore, retraining efforts should prioritize transitioning miners into well-paying jobs, while acknowledging the need for new skills to remain competitive. Mobility presents another challenge: the 2016 Makoszowy mine closure showed that insufficient public transport, low vehicle ownership, and lacking driving licenses limited workers' job search capabilities (Jarzabek 2022).

Although this is Poland's second coal phase-out, previous efforts to retain miners in the labor market had mixed results (Śniegocki *et al* 2022). The 1990s transition was particularly challenging because it was abrupt and poorly planned, occurring within the broader shock of shifting from a planned to market economy. The social consequences were severe—unemployment in Silesia spiked by 7.5% between 1999 and 2003, alcohol consumption increased by one-third nationwide, and suicide rates rose from less than 15 per 100 000 people in 1989 to over 20 in 1997 (Moskalewicz and Zulewska Sak 2003, Bielinska-Kwapisz and Zofia Mielecka-Kubie 2011). While policies like the 1998 Mining Social Package aimed to cushion the impact through voluntary retirement schemes and welfare allowances, they were inadequately designed. For instance, only 419 miners opted for retraining support due to perceived risks. The 1990s transition revealed the fundamental lack of economic competitiveness in a sector that had been artificially sustained under central planning.

This history informs current transition planning, though today's context differs significantly, as workers are better educated, labor shortages are increasing, and more structured support is available through EU Just Transition mechanisms. Policy support must make continued labor market participation more attractive to laid-off workers than leaving the workforce. For example, workers undergoing retraining should continue to be paid. Ideally, employers facing labor shortages should organize and finance retraining programs, potentially guaranteeing employment upon successful completion. This approach would reduce risks for miners, while providing non-mining sectors with a skilled workforce.

5.4. Current research gaps

Based on our analysis, we recommend prioritizing research on the following underexamined issues to better inform Poland's coal phase-out policies:

- **Skills gap**: analyze the skills of miners to prevent unemployment by understanding their preferences and skills needed for future employment (see White 2003, Thursfield and Henderson 2004, Louie and Pearce 2016, Pages 2017).
- **Indirect employment:** study indirect employment and contracting firms to identify vulnerable sub-sectors and explore alternative business arrangements or customers to prevent downsizing or closures (see Mandras and Salotti 2021).
- **Labor shortages vs. layoffs:** assess industries with labor shortages and employment opportunities for laid-off workers (see Morris 2016 for U.S.).
- **Phase-out costs:** evaluate the costs of different phase-out scenarios (see Heinisch *et al* 2021 for Germany).

- **Just energy transition:** investigate the costs and benefits, as well as unintended consequences of the phase-out, with appropriate compensation for the 'losers' of the energy transition (see Broughel and Hampl 2018).
- **Gender aspects**: evaluate the consequences of men's unemployment on women. The coal phase-out may intensify women's existing domestic burdens and increase their vulnerability to gender-based violence, especially as displaced miners turn to alcoholism and substance abuse (see Stanley *et al* 2018). While some studies showed that women's labor force was reduced during a phase-out (they were replaced by men who previously worked in the mines), other studies found an increase in women's share of the labor force due to a reduction of men's employment in mining (see Diluiso *et al* 2021).

6. Conclusion

The transition ahead in Silesia poses a major challenge, with potential job losses affecting up to 20% of the working-age population in the most impacted areas. As a highly industrialized region, Silesia must manage simultaneous industrial, demographic, and environmental transitions while investing in infrastructure and environmental protection to maintain its appeal.

Based on the experiences of Silesia, the EU's largest coal-producing region, this research advances the understanding of industrial transitions in several ways. First, it reveals how demographic decline interacts with employment effects of a coal phase-out, illustrating how labor shortages and unemployment can coexist within the same region. Our analysis draws upon a previously unreported dataset that combines data by Sokołowski *et al* (2022), Frankowski *et al* (2023) and further data from the Statistical Office of Katowice (2023), showing that employment impacts varying dramatically across powiats. Second, for future employment, this research recommends focusing on energy efficiency, automotive, ICT, and other sectors with decarbonization potential, challenging the common narrative that 'green jobs' will absorb fossil fuel sector job losses. Third, it examines indirect employment impacts, highlighting that contractors and service providers in Silesia are highly dependent on single mines, making them particularly vulnerable. Fourth, the research identifies specific barriers to retraining, such as miners' strong resistance to wage reductions and their unwillingness to consider solar or wind sector jobs. The findings emphasize that while green industrial modernization offers opportunities, successful transitions must account for local context, worker preferences, and regional identity.

Silesia's experience offers lessons for other coal-dependent regions, particularly those facing demographic decline like the United States and Germany. The challenges differ for countries with growing populations like Colombia, South Africa, Indonesia, India, and China, where creating alternative employment is even more pressing. There is no accepted coal phase-out blueprint in the Global South. Despite decarbonization targets, new coal plants are built en masse to support growing populations and economies. The key insight from Poland's experience—relevant to all coal regions—is that successful transitions require understanding local contexts, from workers' skill transferability to transportation infrastructure to fiscal capacity. As coal phase-outs become increasingly urgent for climate action, ensuring just transitions is critical for maintaining public support for broader decarbonization efforts.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://doi.org/10.1016/j.eist.2022.03.003, https://doi.org/10.1016/j.resourpol.2023.103693, and https://bdl.stat.gov.pl/bdl/start.

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Appendix

Table A1. Layoffs. Source: Authors' calculations based on Sokołowski *et al* (2022) and the Statistical Office of Katowice (2023).

	Employees (% of current employees)	Miners (% of current miners)	Layoffs (average % of working age population in the affected powiats)	Most affected powiat (layoffs as % of the affected powiat's 2019 population)
Layoffs 2030	45 671 (62.69%)	37 829 (64.40%)	7.35%	Bieruńsko-Lędziński (15.68%)
Layoffs 2040	19 035 (26.13%)	15 118 (25.74%)	3.34%	Bieruńsko-Lędziński (6.79%)
Layoffs 2049	6860 (9.42%)	5497 (9.36%)	1.45%	Bieruńsko-Lędziński (2.74%)

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