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Research article

Hard coal phase-out and the labour market transition pathways: The case of Poland

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ABSTRACT

We study the labour market transition pathways driven by the coal phase-out in Poland between 1990 and 2050. We apply the concept of branching points to describe the coal transition in the context of structural and labour supply changes and educational upgrading. We show that in the 1990s and 2000s, job opportunities for miners were scarce, as the trajectories of all of these trends deteriorated their labour market prospects. As these trends have reversed in the 2010s, the future employment outlook of the coal phase-out in Poland is more favourable than it was in the past. We find that the employment structures of mining subregions and mines are homogenous, which enables regional approaches to manage the transition. Decarbonisation will lead to a surplus of Polish hard coal mining workers from 2030 on, yet the projected shortages of workers in other sectors will create opportunities for reallocation.

1. Introduction

The transition away from coal mining is often associated with negative consequences for the populations of coal-dominated regions, such as surges in unemployment, income declines, and welfare losses. This is particularly the case in Poland, where the initial stage of the coal phase-out overlapped with the country's transition from a centrally planned to a market economy in the 1990s. The socio-economic consequences of the restructuring in the mining sector were amplified by structural shocks across a wide range of industries. Poland is no longer a transition country but a developed economy integrated into global value chains. However, it is important to consider the experience of the rapid closure of coal mining and other heavy industries in planning the future coal phase-out (Johnstone and Hielscher, 2017). Concerns about the socio-economic hardships the 83,000 people who were working in hard coal mining in Poland in 2019 would face if the country decarbonises, remain key obstacles to the transition away from coal (62% of miners are concerned about losing their jobs due to decarbonisation; Kantar Public, 2021). Nevertheless, the extent to which changing conditions and other mega-trends, such as population ageing and structural changes, are altering the socio-economic consequences associated with decarbonisation remains under-researched.

In this paper, we strive to fill this knowledge gap by studying the labour market transition pathways driven by the decarbonisation of the Polish economy from 1990 to 2050. Specifically, we intend to make three key contributions.

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First, we seek to explain the socio-economic context of the early stages of the coal mining transformation in Poland. We examine the labour market trends surrounding the coal phase-out since the start of the transformation of the political and economic system in the early 1990s. We link the changes in the mining industry with three labour market trends that have affected the coal phase-out process: namely, the contributions of mining to total employment, the evolution of the labour supply, and changes in the educational structure. We frame the changes in the mining sector by applying the concept of branching points and pathways (Foxon, 2013).

Second, we assess the level of heterogeneity of individual mines and mining subregions. To implement well-designed transition policies, the relevant stakeholders need to know how similar the mines and the coal-dependent regions are to each other. If they are homogeneous, applying a single approach to transition policies will be sufficient. Thus, we investigate how homogeneous the changes in the employment structures in the mining subregions were between 1990 and 2017. In addition, we analyze how heterogeneous the employment structures of the mines, the industrial plants supporting the mining operations, and the company headquarters were in 2019.

Third, we simulate a transition pathway up to 2050 and look at the decisions that will shape the future of the coal transition in Poland. We construct three labour demand scenarios based on the official plans for phasing out coal that the government and the mining unions have agreed to follow. We base our projections on the two most recent strategic documents determining the future of mining in Poland: the Polish Energy Policy from March 2021, and the agreement between the government and the mining unions from May 2021. Importantly, we use novel data on workers' gender, age, and job position distributions obtained from three major mining companies in Poland. These detailed data allow us to construct bottom-up mining labour supply scenarios, and to account for differences in the pension benefits of different groups of workers. Moreover, we embed these coal mining scenarios to estimate the overall changes in labour supply and demand in the coal-producing Silesia region up to 2050.

Our study has three key findings. First, we show that in Poland, the labour market conditions in which the coal transition is taking place have improved markedly. Between the early 1990s and the mid-2000s, workers who lost their coal mining jobs had poor labour market prospects, as (i) all types of industries were contracting, (ii) large numbers of people of pre-working ages were entering the labour market, and (iii) more than 30% of the working-age population had primary education only. However, since the 2010s, alternatives to employment in mining have increased as other industries, such as manufacturing and construction, have expanded; the growth in the labour supply has slowed down, and the educational structure of the labour force has improved considerably.

Second, we find that the subregions of Poland where hard coal mining has been the dominant industry are better prepared for a future without coal than they were in the 1990s, as they have rebounded from previous declines in heavy industry employment. Moreover, given that in 2019, the hard coal mines were very similar to each other in terms of the age, educational, and gender structures of their workers, the transition away from coal should be easier to manage at the regional or sectoral level.

Third, we show that the 2030 perspective is crucial for phasing out coal in Poland. To ensure that the Polish Energy Policy targets are met, the number of workers employed in mining in the country has to be reduced by 14,000 by 2030. Importantly, other labour market trends in Poland will be conducive to the reallocation of workers. From 2026 onwards, the demand for labour in the Silesia region will surpass the supply, as the region is projected to have a shortfall of at least 20,000 workers each year. This labour shortage should facilitate the occupational mobility of miners. Thus, this future scenario is expected to differ from past periods, when reductions in mining employment coincided with high unemployment rates. Indeed, it appears that an ambitious coal phase-out could help to alleviate labour deficits in other sectors that are expected to grow in the future.

Based on our findings, we offer three policy solutions to facilitate the employment transitions of workers affected by the coal phase-out. First, a hiring freeze in hard coal mining should be implemented. Second, miners should be reallocated from steam to coking coal mines or reskilled to work in similar industries (e.g., the construction or automotive sector). Third, to ease the employment transitions of engineering and technical supervision staff, intersectoral upskilling should be provided. The implementation of these three policy solutions combined can help to resolve the anticipated labour mismatches, and will allow policy-makers to set ambitious decarbonisation targets.

Our paper is structured as follows. In section two, we review the relevant literature. Section three introduces our methodology and data. In section four, we discuss the transition away from coal in Poland since the early 1990s. In section five, we analyze the potential decarbonisation pathways up to 2050. In section six, we discuss the policy implications of our findings. Section seven concludes.

2. Literature review

The scientific and policy debates on the energy system transition evolved from focusing on the technological changes towards integrating social dimensions into energy transformation scenarios. The technical scenarios have aimed to determine the paths of technological changes in the high-emission sectors of the economy. Thus, these scenarios have mainly focused on balancing the supply of and the demand for energy in a given sector (Wesseling et al., 2017). These scenarios tend to be neutral in terms of their socio-economic effects (Rosenbloom and Meadowcroft, 2014). However, a narrow focus on the technology fails to incorporate the broader socio-economic implications of the energy systems transition (Mijin Cha, 2020; Miller et al., 2015; Thombs, 2019). Our study contributes to the literature on energy transitions, highlighting the relevance of labour market dynamics creating the landscape for coal phase-out. We address the need to include the socio-economic aspects of coal phase-out to arrive at an equitable transition to a low-carbon energy system (Henry et al. 2020).

The importance of the social environment surrounding the transformation is emphasized in the multi-level perspective studies. Within this approach, broader contextual trends are defined as landscapes (Geels and Schot, 2007) and are exogenous to actors, industries and policies during the transformation process (Normann, 2019). Nevertheless, the landscape is not static, and even without impulses, the favourable socio-economic setting can create a window of opportunity for transformation (Hölsgens et al., 2018) and

Table 1
The scope of mining company data used in the analysis.

Mining company	Number of active mines in 2019	Share in the total employment in the coal sector in 2019	The dominant type of coal	Time and scope	Source
Jastrzębska Spółka Węglowa	5	26.9%	coking	Complete data on the position and place of work, gender, age, education, work experience, as of 31 December 2019	Data directly obtained from mining companies
Polska Grupa Górnicza	14	49.7%	steam		
Tauron Wydobycie	3	8.2%			
Węglokoks	1	3.2%		Partial data on the position and place of work, gender, as of 31 December 2018	Ministry of State Assets
Spółka Restrukturyzacji Kopalń[1]	-	3.7%			
Other	3	8.3%		The total number of workers, as of 31 December 2018	

Source: Own elaboration.

provide structural 'gradients of force' that introduce possibilities of change (Geels and Schot, 2007; Altunay et al., 2021). We contribute to the socio-technical transitions literature (Markard et al., 2012) as we analyze how the structural, demographic and labour market changes are shaping a favourable landscape for the energy transition.

The low-carbon transition is oriented toward the mitigation of climate change (Geels et al., 2017). Therefore, the transition becomes a disruptive process aimed at phase-out of certain technologies (Rogge and Johnston, 2017). Discontinuity in the energy transition is usually triggered by public policies (Turnheim and Geels, 2012; Kivimaa and Kern, 2016; Bjerkan et al., 2021). Policy-makers take key decisions in response to the external stresses or triggers and determine the transition pace (Foxon et al., 2013). We use the example of Poland to identify the critical decisions taken during a historical coal transition pathway between the 1990s and 2020 and explain the context of transition to a low carbon economy beyond the 2020s.

Decarbonization also results in a labour market churning, as miners' workplaces are reduced. A key labour market policy challenge is to secure an alternative employment opportunity for the workers affected by the coal phase-out (Andersen and Gulbrandsen, 2020). Therefore, coal phase-out policy requires considering processes associated with the transformation itself, e.g., labour market changes, industrial dynamics and inter-sectoral linkages, and existing knowledge bases ((Andersen et al., 2020)). The alignment of social and economic goals, such as jobs and value creation, is crucial for the social legitimacy of transitions (Foxon, 2017; Busch et al., 2018).

The primary focus of recent research on decarbonisation in Poland has been on evaluating the technological changes referring to the decline of coal use (Antosiewicz et al., 2020; Kiuila, 2018; Safarzyńska and van den Bergh, 2010) or on describing the regulatory context of the transformation (Sokołowski, 2018). Several studies have examined the socio-economic implications of the coal phase-out by investigating the spill-over effects of coal mines closures in Poland (Winkler, 2019; Alves Dias et al., 2021) and the distributional effects of decarbonisation (Antosiewicz et al., 2022). Some studies investigated attitudes (Żuk et al., 2021) and socio-technical imaginaries (Kuchler and Bridge, 2018), as well as the political economy of coal transition in Poland (Brauers and Oei, 2020). The studies on the Polish phase-out has also investigated the roles of the relevant stakeholders and main narratives concerning this process (Żuk and Szulecki, 2020; ; Furmankiewicz et al., 2021). While our work takes stock of this previous research, we demonstrate that even though efficient decarbonisation depends on the availability of viable technological and labour market alternatives, the socio-economic context surrounding the transition should be taken into account.

3. Methodology and data

We followed three steps to identify the labour market transition pathways driven by the coal phase-out in Poland between 1990 and 2050. First, we introduce our data (Section 3.1) and define branching points as windows of opportunity (Section 3.2). Second, we explain the assumptions behind the hard coal phase-out scenarios in Section 3.3. Third, we decribe the methods to analyze within-sector heterogeneity of employment structures at a local level (3.4).

3.1. . Data sources

We use data on employment in the mining industry provided by the Ministry of State Assets and the largest Polish coal companies. Our data contain information on the general structure of employment in the mining industry, broken down by gender, position, and place of work (Table 1). We have accessed novel data from the coal companies on the age, tenure, and educational structures of mining workers at the level of individual plants. Our data cover 90% of all employment in the mining industry, and we analyze these data broken down into workplace types (i.e., underground workers and surface workers); and further disaggregated into (1) miners (blue-collar workers), (2) engineering and technical supervision staff, and (3) administrative staff.

[1] Spółka Restrukturyzacji Kopalń (SRK) acquires mines to restructure employment; therefore, it employs miners but does not have any active mines.

Table 2
Description of the data applied in the analysis.

Indicator	Definition	Disaggregation	Timeframe
Employment	All persons engaged in some productive activity	Poland Mining subregions	1992–2017
Population of pre-working and retirement ages	Ages at which people are not yet able to work (0–17 years), and ages at which most people have stopped working (65 years and older for men, 60 years and older for women)	Poland Silesia region	1993–2018 1995–2018
Education	Share of people according to the highest education level achieved	Poland Mining subregions	1995–2018
Use of hard coal in the economy	Past and projected use of coal in the economy broken down into three main end-users: electrical energy and heating, households, industry, and others	Poland	1990–2050
The productivity of hard coal mining	Past and projected productivity of coal extraction		2019–2050

Source: Own elaboration.

Table 3
The methodology of branching points applied in the analysis.

Branching point	Time frame	Emerging tensions	Critical choices	Competing interests
A window of opportunity to reorient decarbonisation	When did it happen? How long did it influence the pathway?	The circumstances surrounding the branching point	What decision was made to resolve it? What choices are available to resolve it?	Arguments of the stakeholder *G* Arguments of the stakeholder *U*

Source: Own elaboration based on Foxon (2013), and Rosenbloom (2017).

We focus on three levels of administrative disaggregation: (1) Poland, (2) the Silesia region, and (3) the mining subregions. We have chosen the Silesia region as our focal point because the majority of Polish hard coal extraction is concentrated there. When examining the mining subregions, we note that seven out of eight subregions of the Silesia region[2] had at least one active steam coal mine in the 1990–2021 period. While the subregional level is more vulnerable to structural changes and is more relevant to policy discussions about the coal transition processes than the other levels, it is rarely considered due to data constraints. The disaggregation level we apply depends on the data availability (Table 2).

3.2. Branching points: an analytical category of transition pathways

We apply branching points to understand the transition process and to embed the current and future changes in a historical perspective (Foxon et al., 2013). We define a branching point as a window of opportunity whose outcome is influenced by a politically mediated choice taken in the presence of alternatives (Foxon and Hammond, 2010). Resolving branching points leads to the orientation of system configurations along new pathways. Branching points demonstrate how actors can allow their decisions to be shaped by the future pathways towards decarbonisation (Table 3). Competing interests and visions for the future determine the critical choices regarding the energy sector. We use the aforementioned concept to analyze the emerging socio-economic patterns and examine how these pressures open branching points for low-carbon pathways (Rosenbloom, 2017).

3.3. Scenarios of labour supply and demand in the mining sector, and in the Silesia region

3.3.1. Labour supply in mining

We base the mining labour supply scenario on the assumption that workers will retire when they reach the full retirement age. This approach has been used in research on the German lignite coal sector (Haywood et al., 2021). In this paper, we have applied precise data on the gender, age, and job position distributions of workers. As these data were collected directly from mining companies, they allowed us to account for the differences in the pension benefits of underground and surface workers. The main assumptions of the labour supply scenario are as follows:[3]

(1) the admission of new workers into the sector is halted.
(2) all of the workers employed underground are miners.
(3) all of the underground workers retire at the moment they reach the full retirement age for miners of 50 years (we assume they have achieved the necessary tenure in mining and/or equivalent work).

[2] The seven subregions are: Bielski, Bytomski, Gliwicki, Katowicki, Rybnicki, Sosnowiecki, and Tyski. We excluded the Częstochowski subregion from our analysis.
[3] We provide the formula in Appendix A1.

(4) all of the surface workers retire according to the regulations of the general pension system in Poland: i.e., men at the age of 65, women at the age of 60.
(5) the retirement age regulations for miners and the general population do not change.
(6) workers will not leave work on their own or move to other mines.
(7) production will be specialised: i.e., some plants will only produce steam coal or coking coal.

To ensure that our scenario assumptions are realistic and relevant, we have consulted them with sectoral and labour market experts operating in mining areas[4] at the international energy workforce modeling seminar. Our data enabled us to capture detailed differences among mining workers. To the best of our knowledge, our study is the first labour supply projection of the hard coal employment in Poland, disaggregated by occupational groups and gender, and built bottom-up using firm-level employment data.

3.3.2. Labour demand in mining

The demand for coal in Poland stems mainly from the energy sector. In 1990, about 90% of energy production was through the burning of hard coal and lignite, mostly extracted from Polish mines (Manowska et al., 2017). We have prepared a scenario for the demand for labour in hard coal mining based on the available decarbonisation projections from the Polish Energy Policy 2040.[5] The starting point for the scenarios is the structure of mining, coal consumption, and employment in mining based on the data available at the end of 2019. In the scenarios, we develop paths of hard-coal mining employment to achieve decarbonisation. In each scenario, we assume an annual increase in labour productivity in mining at a level of approx. 2% (Humphreys, 2020).

The pace of decarbonisation in the Polish economy will mainly depend on two factors: the prices of CO_2 emission allowances, and political decisions regarding the energy sector. We have prepared two scenarios based on the Polish Energy Policy 2040 projections:

(1) Labour demand (1): scenario of high CO_2 emission allowance prices.
(2) Labour demand (2): scenario of sustainable growth of CO_2 emission allowance prices ((Ministry of Climate and Environment, 2021)).

Additionally, we developed a third scenario based on the agreement between the government and the mining unions: Labour demand (3): mine closure schedule. Under this agreement, 19 hard coal mines will be closed in the 2021-2049 period.[6] The scenario takes into account the process of mine closure over ten years, with employment being held at a constant level (compared to 2019); and employment being reduced to 10% in the year the mine closes (compared to the previous year), and to 2% over five years after closing based on the employment trends in the closed Polish mines. Maintaining employment at a certain level after the exploitation of coal ends is expected to ensure the stability of the mining area (World Bank, 2018a).

3.3.3. Labour supply and demand in the Silesia region

We use the results of the System of Forecasting the Polish Labour Market project (System of Forecasting the Polish Labour Market, 2021) as the projection of the future changes in the general supply of and demand for labour in Poland up to 2050. The labour supply forecast is based on three mechanisms that influence the number of workers with specific qualifications. First, the demographic model allows us to forecast the population in single age groups while taking into account fertility, mortality, and migration. Second, we model the educational decisions by assigning the level of education to specific cohorts of the population. Third, the model of educational and professional flexibility allows us to translate the expected levels of education to occupational profiles, and to forecast the potential number of workers in a given occupation. Finally, the demand for labour is estimated for four sectors of the economy (agriculture, industry, market services, and non-market services), and accounts for the number of workers in each sector, the gross value added, and the gross value of fixed assets (Antosiewicz et al., 2019).

3.4. Heterogeneity measure – the Euclidean distance

We analyze the heterogeneity of the mining subregions and the mining sites with the (1) Euclidean distance:

$$d_{(x,y)} = \sqrt{\sum_i (x_i - y_i)^2}$$

where, $d_{(x,y)}$ is the distance between points x and y in the cartesian space, and i is either a selected mining subregion or site. First, we calculate the Euclidean distance in the mining subregions between employment structures in 1990 and 2017, and their average structure in each year. Second, we supplement the analysis with the calculation of the Euclidean distance in the structure of employment, age, gender, and education between each mining site and the sectoral average.

[4] Including the president of the board responsible for coal industry monitoring and human resources officer from the largest hard coal mining company.
[5] We provide the formula in Appendix A1.
[6] We describe the schedule in Appendix A2.

Table 4
Transformation of coal mining in Poland 1990–2018.

Branching point	Timeframe	Emerging pressures and tensions	Critical choices	Competing interests
Pre-transformation	1990 - 1992	Increasing the profitability of the mines and orienting them towards the market	Operating as single companies	Increasing profitability and productivity
From central planning to a market economy	1993 - 2004		Grouping the mining companies into mining conglomerates	Sustaining wages and employment
Competition on international and internal markets	2005 -2018	Increases in coal imports and decreases in coal exports	Securing the energy supply with domestic coal production and use	
		Changes in the energy mix towards cleaner technologies	Deployment of renewable energy sources	Meeting the targets of the European Union's energy policy

Source: Own elaboration.

4. Coal transition in Poland since the early 1990s

First, we describe the transformation of the mining sector in Poland between 1990 and 2018. Second, we link the past transformation pathways to the stylised facts on the labour market changes in Poland. Third, we show how the employment structure in the hard coal mining subregions has changed since the 1990s. Fourth, we analyze the most recent structure of mining employment and assess the differences between the mining sites.

4.2. Decarbonisation pathways 1990–2018

The structural changes in the Polish economy that began around 1990 affected the hard coal mining industry. The restructuring of the industry reoriented it away from the dominance of strategic state-owned companies, and towards market demands and profit maximisation (Mazurkiewicz, 2006; Dubiński and Turek, 2017). The transformation of coal mining aimed to increase the productivity and profitability of the mines. The hard coal mining industry was never fully commercialised and remains under state control in 2022. As a result, the state remains the main actor in transforming hard coal mining in Poland.

We distinguished two periods of coal transformation in our analysis (Table 4). First, we treat the decision to form mining conglomerates in 1993 as the beginning of the actual mining sector transformation in Poland. The formal transformation of the mining sector started in 1990 and ended in 1992, as an experiment in allowing the mining companies to operate as autonomous entities on the market turned out unsuccessful (Kosmalski, 2003). It proved that without a coordinated policy, coal companies were not able to adjust to the market economy setting. In 1993, the mines formed conglomerates and started to reduce their production capacity, employment, and non-productive assets (Blaschke and Gawlik, 1999; Ürge-Vorsatz 2006; Korski et al., 2016). The coal conglomerates were established based on the spatial proximity and the type of coal produced (broken down into coking and steam coal). Up to 2000, the restructuring processes were conducted within these conglomerates (Brauers and Oei, 2020; Jonek-Kowalska, 2015). In the mid-2000s, two additional entities were set up to take over liquidated plants, monetise assets, and re-cultivate the land. In the first period of transformation between 1990 and 2004, 35 mines were closed, the production was reduced by half, and 184,000 workers were dismissed (Paszcza, 2010).

Second, the accession of Poland to the EU in 2004 changed the institutional context for coal mining in terms of market regulations and state aid rules (Hayo, 2004; Skoczkowski et al., 2020). The depletion of coal resources and the deterioration of the geological conditions of coal production, the pressures of mining in highly urbanised areas, and wage rigidity all contributed to increases in coal production costs (Manowska et al., 2017; Wierzbowski et al. 2017; Jonek-Kowalska 2018). Moreover, fluctuations in the international coal market strongly affected the economic performance of hard coal companies between 2005 and 2018. Price volatility contributed to decreases in the export of Polish coal and to increases in coal imports, which exacerbated the trade imbalance and limited domestic sales. At the same time, the development of renewable energy sources affected the effort to decrease the share of coal in the energy mix (Jaskólski 2016; Wierzbowski et al. 2017). Although new energy sources were built, the demand for coal did not decrease considerably due to the coal dependence of the Polish energy sector and the unions' political influence on energy companies (Rollert, 2018). Structural changes and further privatisation were supposed to recover the sector's performance. Mines were further incorporated into energy companies' supply chains or grouped into conglomerates (Kamiński and Kudełko, 2010). Between 2005 and 2018, coal production decreased by 35%, and 40,000 coal sector jobs were eliminated (Szpor and Ziółkowska, 2018).

The transformation of hard coal mining in Poland between 1990 and 2018 had impacted the coal-mining regions of Poland. Two notable examples serve as an important experience for planning the future transition. First, between 1990 and 1996, the coal basin located in the Wałbrzych region was closed, and more than 10,000 people were dismissed from local coal mines. The process lacked a labour market transition strategy and led to substantial socio-economic hardship (Lesiw-Głowacka et al., 2021). The unemployment rate increased from about 11% in 1990[7] to 17% after the last mine closed in 1996. The experience of the Wałbrzych region showed that the transformation of mining regions requires a well-structured labour market strategy, considering the needs of released workers and a structural policy for economic diversification of the region. Second, in the Silesia region, the most intense employment decline in the

[7] Own calculation base on Statistical Office in Wałbrzych (1998), and Zakrzewska-Półtorak (2010)

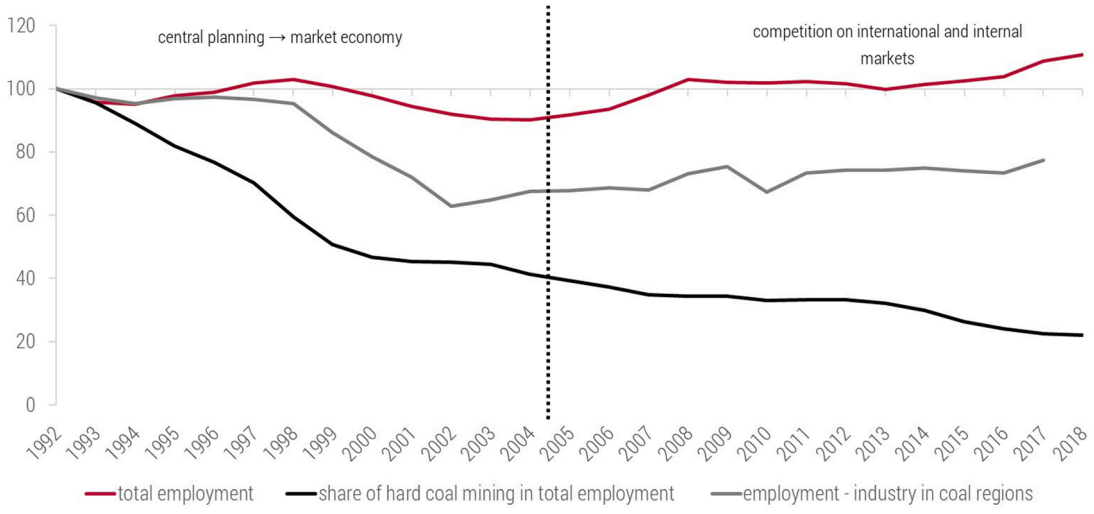

Fig. 1. The dynamics of employment: total, mining, and industry in the mining subregions, 1992–2018 (%; 1992 = 100).
Notes: The Labour Survey data are available from 1992 onwards. The last available data from the ERD Eurostat are from 2017. Source: Own calculation based on the Statistics Poland and the ERD Eurostat data (2021).

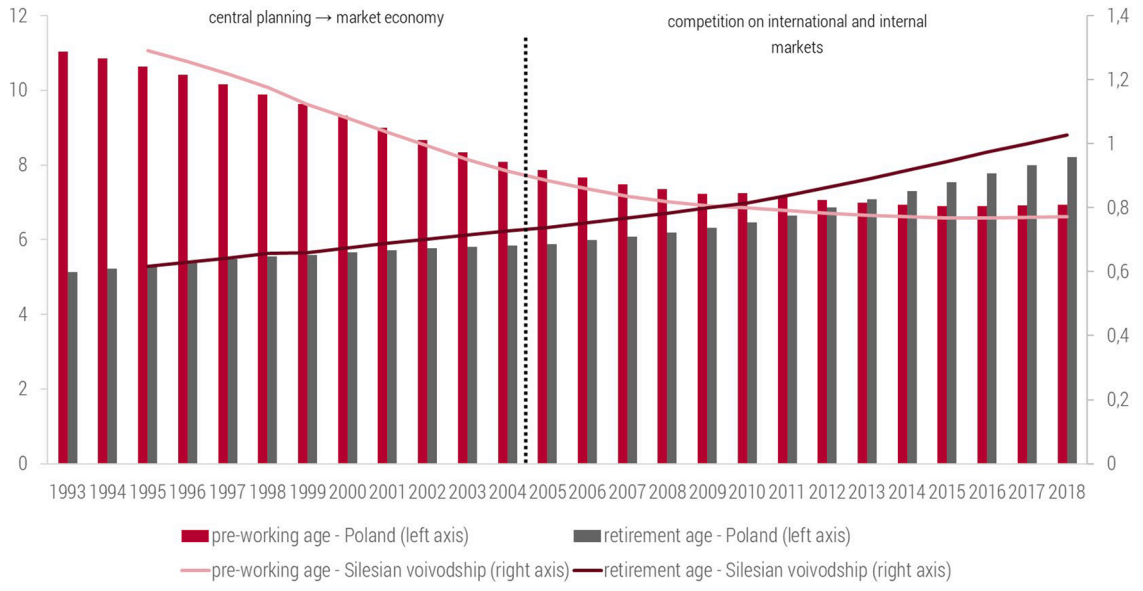

Fig. 2. The number of people of pre-working and retirement ages in Poland 1993–2018 (millions of people).
Note: The first available data on the Silesia region are from 1995. Source: Own calculation based on the Statistics Poland and the ERD Eurostat data (2021).

mining industry occurred at the turn of the 1990s and 2000s. Employment in hard coal mining decreased by over 100,000 people between 1998 and 2002. Unlike the Wałbrzych region, a large-scale labour market policy package was consulted with the mining trade unions and then implemented. Between 1998 and 2002, approx. 67,000 workers benefited from labour market support. However, the mitigation measures were insufficient to maintain a high level of economic activity of workers leaving the mining industry. The main failures of this initial coal transition stage in the region of Silesia were: the lack of targeted active labour market policies (Szpor and Ziółkowska, 2018), an insufficient public intervention aimed at revitalization and economic recovery in the most affected cities (Krzysztofik et al., 2012), and misrecognition of the socio-cultural determinants in the mining communities (Faliszek et al., 2001).

However, these assessments of employment reforms in the Polish coal mining in the 1990s usually do not account for the overall labour market trends, even though the socio-economic setting surrounding the transition process affects the pace and effects of the coal-phase out process. In our study, we highlight the importance of the labour market trends which contribute to the landscape of the energy transition. Also, while acknowledging the experience of the Wałbrzych hub, we focus on the Silesia region, which houses the

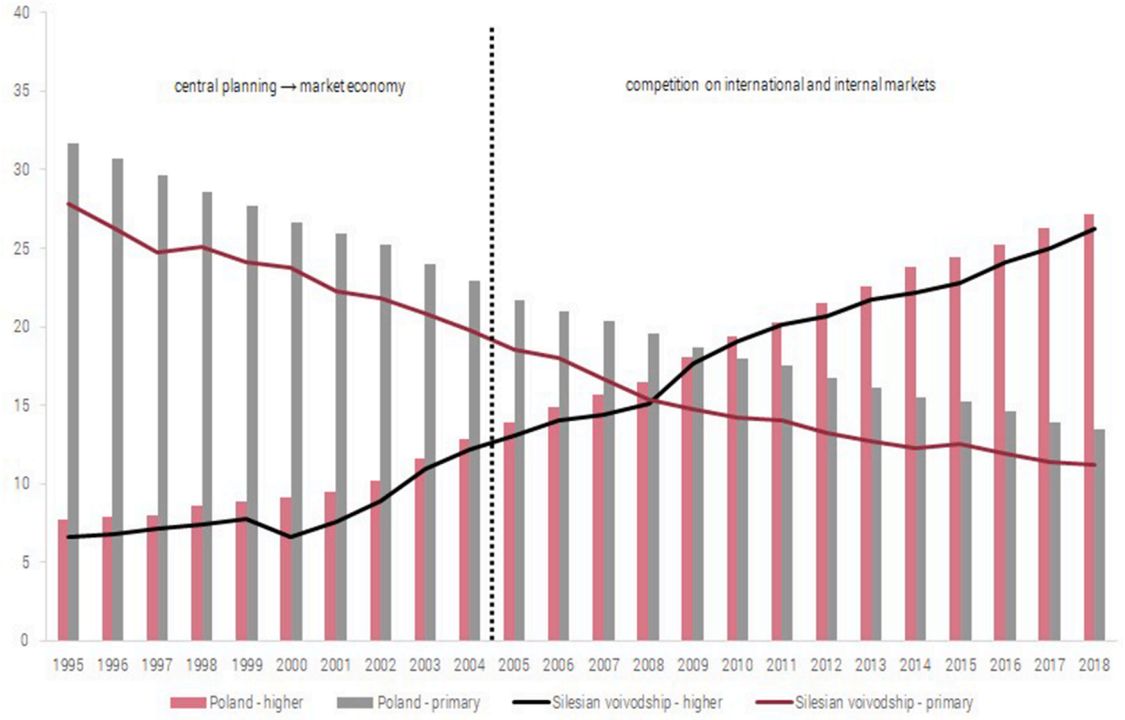

Fig. 3. The share of people aged 15-64 with higher education or primary education only in Poland and the Silesia region 1995–2018 (%). Note: The first available data are from 1995. Source: Own elaboration based on the Statistics Poland data (2021).

vast majority of remaining hard-coal mines in Poland.

4.3. The trends in employment in Poland 1990–2018 that affected the transformation of the coal mining industry

We have identified three major labour market trends that influenced the context of employment transformation in hard-coal mining between 1990 and 2018 in Poland: (1) the share of employment in mining in total employment, which reflected the dynamic of this sector and its relevance for the total economy during particular decarbonisation phases; (2) the labour supply; and (3) the educational structure, which determined the availability of labour market opportunities for workers who lost their mining jobs.

First, total employment was gradually decreasing during the first period of the transformation of the mining sector, with the largest decline (by 10 p. p.) occurring in 2004 (Fig. 1). At the same time, the share of coal mining employment in total employment and employment in industry in the coal subregions has constantly been decreasing. Finally, the economic contribution of mining has been plummeting as well: the contribution of mining and extraction to the Polish GDP (the mining and extraction gross value-added share in the total GVA) decreased from 6.6% in 1990 to 1.7% in 2018.[8]

Second, the labour supply has constantly been decreasing since the 1990s. At the beginning of the coal sector transformation, more young people were entering the labour force than older people were retiring (Fig. 2). In the first phase of the coal mining transformation, the closing of mines and the reduction of jobs in the mining industry placed additional pressure on the labour market. Since 2013 (2010 in the Silesia region), the number of people of retirement ages has surpassed the number of pre-working ages inhabitants. Thus, in recent years, reductions in employment in the mining sector have released the additional workers needed to ensure economic stability, rather than creating a structural labour mismatch that could not be managed efficiently.

Third, the structure of educational attainment has changed substantially since the beginning of the mining transformation in Poland. In 2018, the Silesian population had higher education and competency levels, which meant that more people had attractive alternatives to coal sector employment. In the early 1990s, almost half of the Polish population had primary education only (Fig. 3). In the subsequent phases of the coal mining transformation, the share of people with higher education grew considerably. Since 2010, the share of people with higher education in Poland (and in the Silesia region where the shift was in 2008) surpassed the share of people with primary education only. This growth was driven primarily by young people entering the labour market, as, by 2011, 30% of

[8] We use the GVA of mining and extraction only as a proxy indicator of the importance of coal for Polish economy, since the "mining and extraction" section also covers the extraction of other natural resources, especially copper. Thus, while the contribution of hard coal mining and extraction to the economy is presumably smaller, we cannot support this assumption with data (Statistics Poland, 2021).

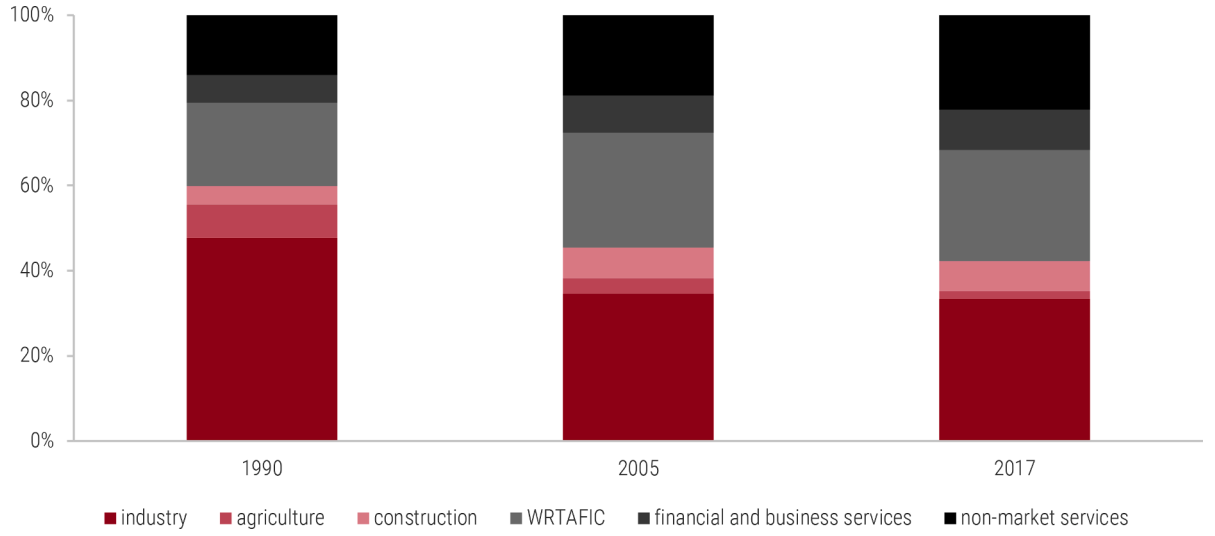

Fig. 4. The employment structure in 1990 and 2017 in the mining subregions (%).
Note: The last available data from the ERD Eurostat are from 2017. WRTAFIC – wholesale, retail, transport, accommodation, food services, information, and communication. Source: Own elaboration based on the ERD database (Eurostat, 2021).

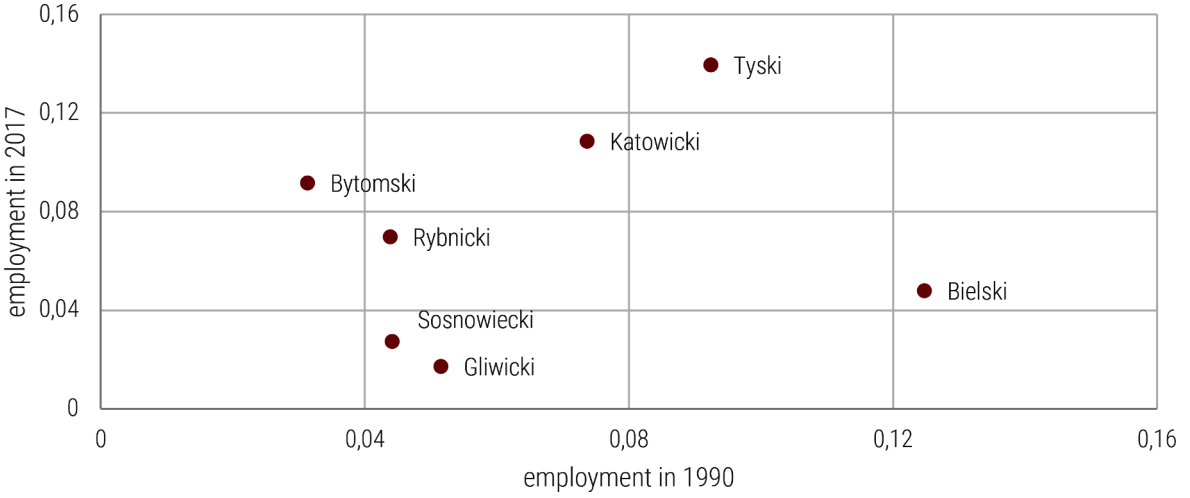

Fig. 5. The Euclidean distance between the mining subregions and their average structure of employment.
Note: The last available data from the ERD Eurostat are from 2017. Source: Own elaboration based on the ERD database (Eurostat, 2021).

people in this age group had higher education.[9]

4.4. The structure of employment in the mining subregions 1990–2017

The structure of employment in the mining subregions of the Silesia region changed considerably between 1990 and 2017. Employment in the mining industry underwent the largest shift, declining by 15 percentage points. The share of employment in all sectors other than industry and agriculture increased. The majority of the changes in the mining industry occurred in the first phase of the coal sector transformation up to 2005 (Fig. 4).

To demonstrate the changes in the employment structure in the mining subregions, we calculated the Euclidean distance between their employment structure and the subregional average in 1990 and 2017 (Fig. 5). The employment structures of the mining subregions underwent major changes, with two exceptions. First, one subregion (Bielski) stood out in 1990, but its employment structure had converged towards the subregional average by 2017. Second, the employment structure of the Tyski subregion differed from that

[9] Appendix A3 provides statistics on the highest level of education achieved by people aged 20–29 based on the census data.

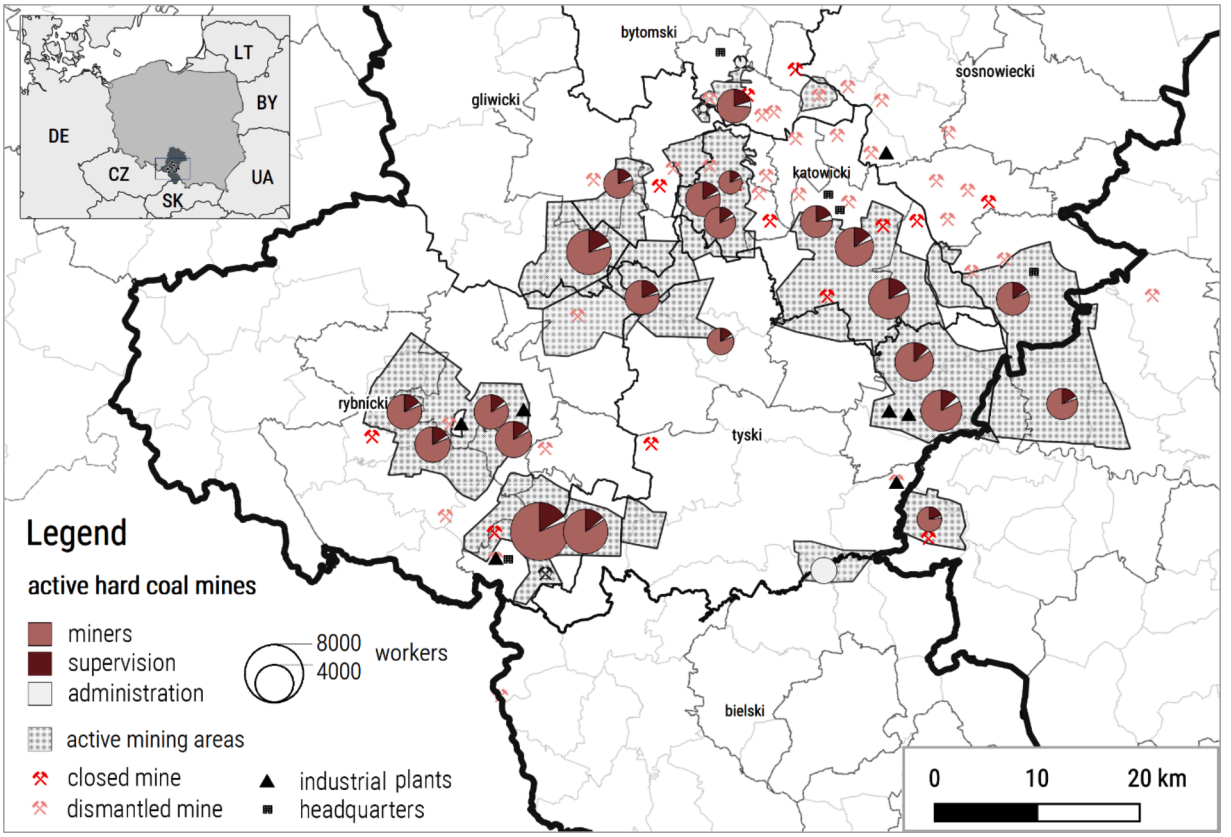

Fig. 6. The spatial distribution and the structure of mining employees by subregion and job position in 2019
Source: Own elaboration based on the data obtained from mining companies.

of the other subregions in both 1990 and 2017. These divergent patterns were due in part to the socio-economic characteristics of these subregions, as their economic activities were less oriented towards mining and were more focused on the automotive industry and services (Frankowski and Mazurkiewicz, 2020).

4.5. *Employment in mining 2019*

In 2019, half of all coal sector workers and three out of four hard coal mining workers in the EU worked in Poland (Alves Dias et al., 2018). At the end of 2019, 83,000 people were employed in hard coal mining in Poland, with the vast majority (89%) working in seven mining subregions in the Silesia region (Fig. 6). Of the workers in the mining sector, 77% were blue-collar workers, 17% were engineering and technical supervision staff, and 6% were administrative workers. Most of the mining sector workers in the region were working in mines (94%), while the remaining 6% were working in coal processing plants and administration.

In 2019, the average age of a hard coal mining worker in Silesia was 39 years, with a substantial age gap between underground (36) and surface workers (48). The average age of the workers was low because miners can retire earlier (at the age of 50)[10] than people employed in other industries (who usually retire at the age of 60 or 65). Men working as underground workers represented the most numerous group within the sector (Fig. 7). Women made up only 10% of all coal sector workers, with the vast majority working on the surface as blue-collar or administration workers. Most of the women still employed in the coal sector will reach retirement age in the current decade.[11]

Polish hard coal mines are similar to each other in terms of the age structure, education, and gender of the workers employed in various positions underground and on the surface (Fig. 8). We observe slight differences between the mines and the industrial plants supporting the mining operations or the administrative headquarters. The similarities between employment structures in the

[10] Or after 25 years working in the mining sector, and at least 15 years working underground.
[11] As across the whole sector, only slightly more than 100 women are working underground, mostly in technical supervision roles, these are exceptional cases.

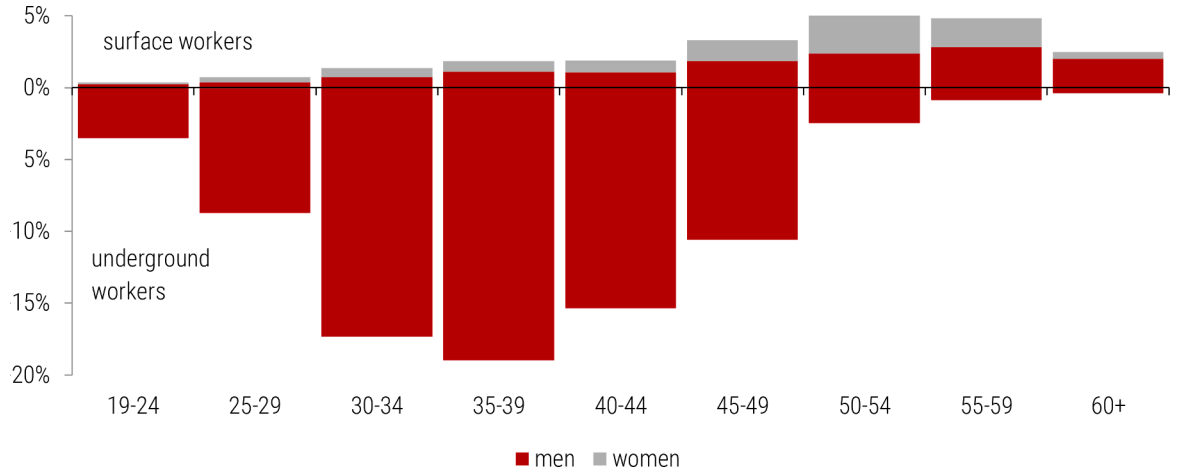

Fig. 7. The structure of employment in hard coal mining (%).
Source: Own elaboration based on the data obtained from mining companies.

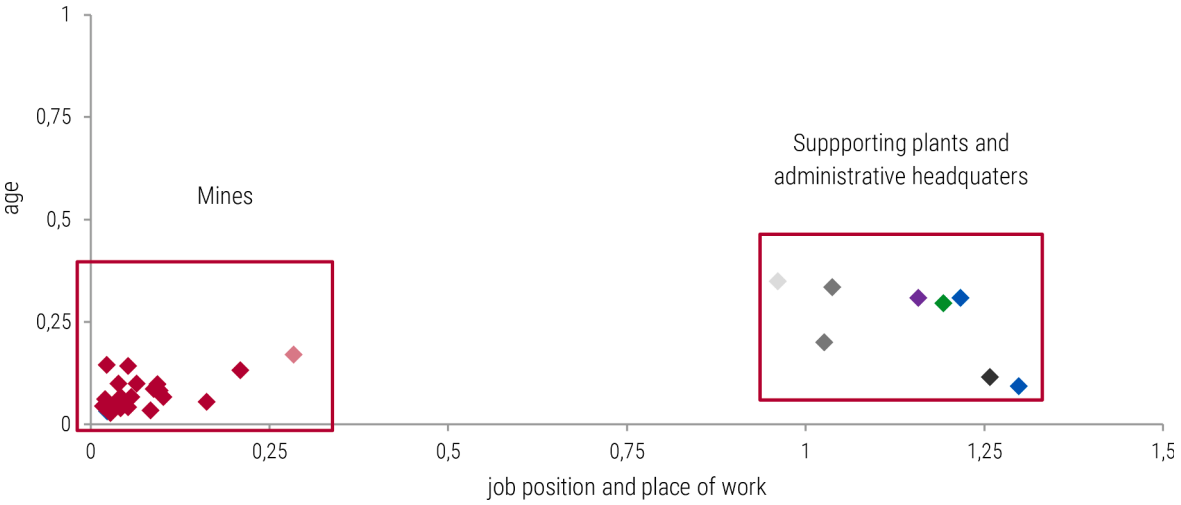

Fig. 8. The Euclidean distance between age and job position and place of work.
Source: Own elaboration based on the data obtained from mining companies.

homogeneous group of mines are slightly higher in terms of gender and job position/place of work and are lower in terms of education and age.[12] The homogeneity of the employment structures do not affect the order in which the mines may be scheduled for closure, which suggests that a single approach can be applied to the labour transition policies in the decarbonisation process.

Miners in Poland are a well-organised group with a relatively rational attitude: they appreciate work benefits, stability, and earlier retirement possibilities (Kantar Public, 2021), and highly assess their skills and chances on the labour market if a mine closes (Kiewra et al., 2019). Additionally, the mining unions were able to strike an agreement with the government on a coal phase-out which proved their ability to support transformation in exchange for a progressive regional development policy.

5. Decarbonisation pathways and employment in mining up to 2050

Based on the demographic and educational structure as well as labour supply trends, we have demonstrated that labour market conditions in Poland are much more favourable for decarbonisation currently than they were in the past. This section focuses on the possible decarbonisation pathways in Poland, the branching points of future coal transition, and the associated labour market changes up to 2050.

[12] Two additional figures on the Euclidean distance between education and job position and place of work, and between education and job position and place of work, are in Appendix 3.

Table 5
Transformation of coal mining in Poland 2019–2050.

Branching point	Time frame	Emerging pressures and tensions	Critical choices	Competing interests
Energy mix diversification	2019–2040	Decarbonisation of the energy sector laid out in the Polish Energy Policy 2040 Delaying decarbonisation and breaching the international and EU-level climate agenda	The pace and the time frame for phasing out coal	Securing energy supply through "clean" coal technologies Securing energy supply without coal Sustaining the miners' wages and employment Responding to surges in energy prices due to increases in the prices of CO_2 allowances
Managing the labour mismatch via support policies	2019–2040	Reduction in mining employment and the need to increase the labour supply in other sectors of the economy	Retraining miners to sustain the labour supply Stopping the hiring of new workers	Welfare losses through reductions in retirement benefits, employment stability, and/or lower wages
	2030–2050	Shortages of engineering and technical supervision staff	Intra-industry retraining and staff reallocation Providing miners with early retirement benefits	Workforce losses and decreasing labour market participation

Source: Own elaboration.

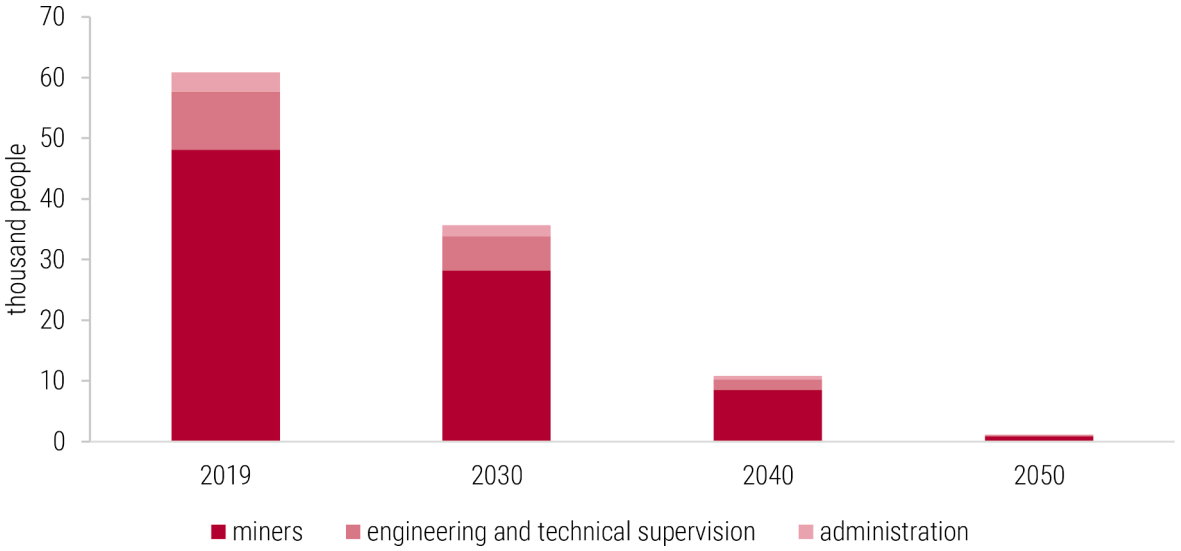

Fig. 9. Projection of the size and the structure of hard coal mining employment in Poland.
Note: The structure projections refer to the natural outflows to retirement scenario. Source: Own elaboration based on the data obtained from mining companies.

The current phase of the structural changes in the Polish mining sector started around 2018 and 2019, when the European Commission announced the aim of reaching carbon neutrality by 2050 (European Commission, 2018). Achieving this goal will require the decarbonisation of the Polish economy. The European Commission proposed a set of policy solutions to incentivise the phasing out of coal, in particular the measures proposed in the European Green Deal and the Just Transition Fund (Loonela, 2020). Since then, the Polish administration has negotiated decarbonisation scenarios with the mining unions, and has announced two sets of strategic goals: the social agreement between the government and the unions that contains the mining closure schedule, and the Polish Energy Policy 2040. We interpret these strategic decisions according to the methodology of branching points (Table 5), and discuss their effects on the decarbonisation pathways up to 2050, in the following sections of the paper.

Our simulation scenarios show that the retirement of miners who are currently working will serve as the key channel of reductions in mining employment. However, these outflows to retirement are not sufficient to meet the declining demand for labour in either of

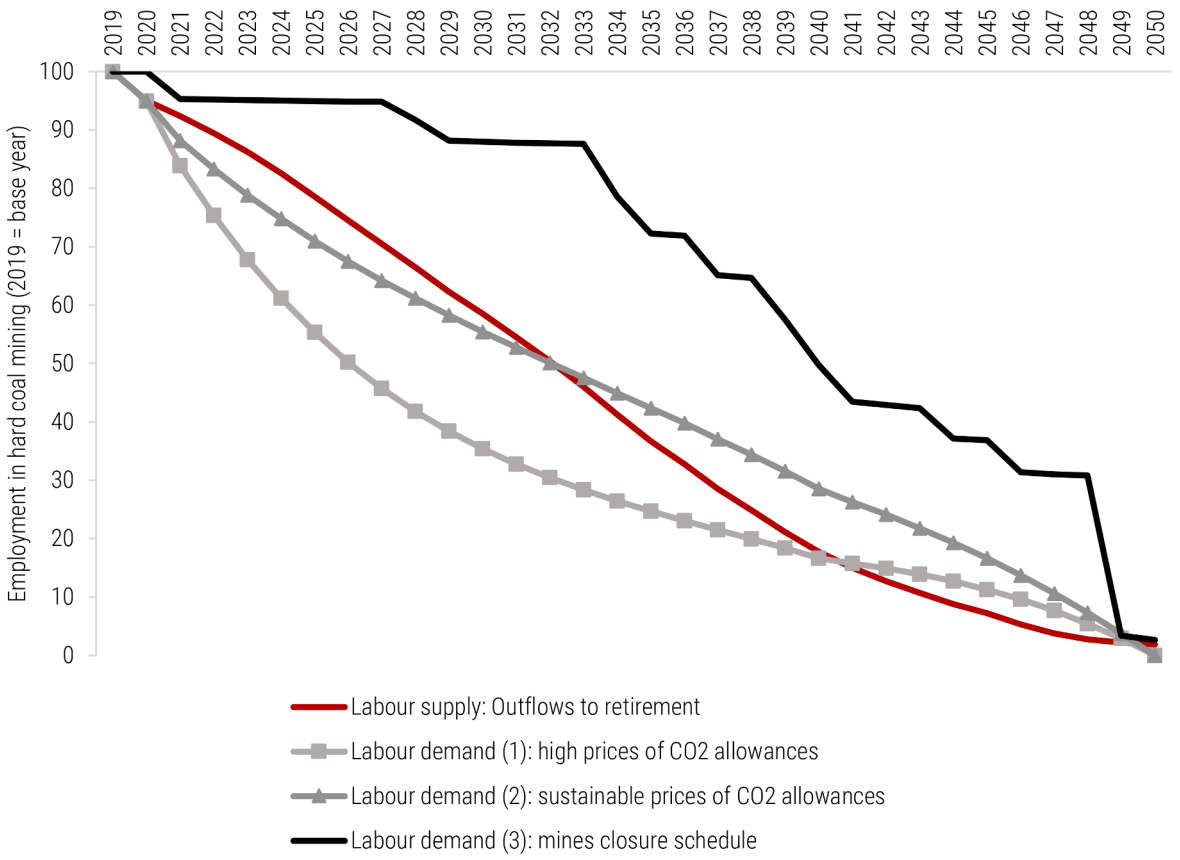

Fig. 10. Scenarios of labour supply and demand in hard coal mining, 2019–2050 (%).
Note: In the mine closure schedule scenario, we assume that in each mine, employment remains constant at the 2019 level until the year of its closure. Source: Own elaboration based on the data obtained from mining companies.

the two proposed decarbonisation scenarios in Poland up to 2050.[13]

As large shares of the ageing mining workforce will reach the full retirement age for miners in the coming decades, substantial changes in the mining sector labour supply are projected to occur in Poland by 2030 and 2040. Thus, the number of workers in the mining sector is expected to decline substantially due to outflows to retirement. First, more than 40% of the currently employed miners will have retired by 2030. Second, these outflows to retirement will be followed by major changes in the employment structure in the mining sector after 2030. A shortage of engineering and technical supervision workers is likely to occur by 2040, as the share of these workers in total employment is projected to decrease from 17% in 2019 to 9% in 2040 (Fig. 9). Importantly, the contributions of these workers will be crucial to the everyday operations and maintenance of the mines and the coal phase-out process, as they will supervise the closure of the mines.

In Poland, phasing out coal according to a specific transition pathway is expected to lead to one of three of the following branching points (Fig. 10).

First, based on the assumption that the prices of the CO_2 allowances will increase sharply, a surplus of as many as 14,000 workers in 2030 could occur. This pathway would enable the Polish economy to decarbonise earlier than in 2050. Meanwhile, the number of workers leaving mining will be manageable if targeted labour market policies are implemented (Frankowski et al., 2021).

Second, if the value of the CO_2 allowances grows at a moderate pace, a surplus of 2000 workers is projected to occur up to 2030. Importantly, after 2030, this lower initial labour surplus will turn into a substantial shortage of workers in mining, which will continue up to 2050. Under these circumstances, delaying the pace of decarbonisation reduces the short-term surplus of workers, but it creates other mismatches after 2030. Thus, unless the pace of decarbonisation proposed in the government's strategy increases sharply after 2030, the industry will have to employ new miners after a decade of layoffs to meet the demand for coal. In both CO_2 price scenarios, the largest labour surplus in mining will occur by 2030, despite a significant reduction in the labour supply due to outflows to retirement.

[13] The reduction in mining employment will be supported by the Miners' Social Package (a component of the agreement between unions and the government) by providing a "miner's leave" (early retirement) or a one-off severance payment for mining workers who decide to quit their jobs.

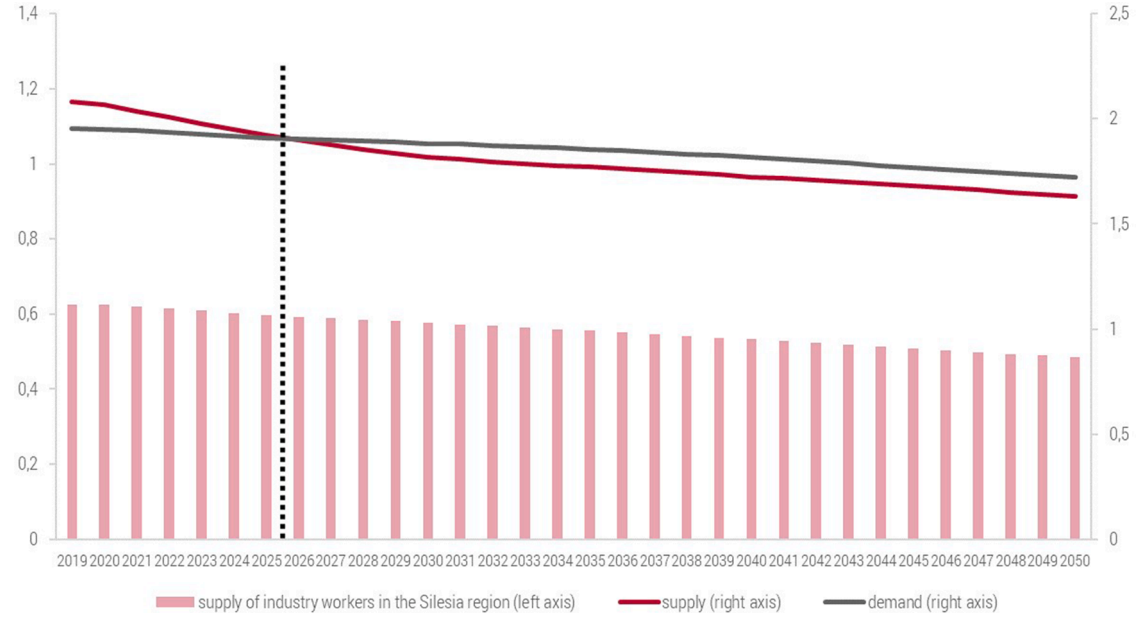

Fig. 11. The projection of labour supply and demand in the Silesia region up to 2050 (millions of workers).
Source: Own elaboration based on the System of Forecasting the Polish Labour Market (2021).

Third, there are no decisive steps towards phasing-out coal in the schedule agreed upon by the government and the mining unions. Under this plan, three mines will close up to 2029, nine will stop operating between 2034 and 2046, and the last five – including the biggest steam coal mine in Poland – will stop extraction in 2049. The projected labour demand in this plan greatly exceeds the labour demand pathways in all other decarbonisation scenarios, especially in the short term, i.e., up to 2030. In addition, as the mining labour demand under this agreement exceeds the mining labour supply, more mining workers will have to be hired, especially in the 2020s (Fig. 10).

Notably, the anticipated surplus of workers in the Polish hard coal mining will be accompanied by shortages of workers in other industries, particularly in the coal-producing region of Silesia. According to the System of Forecasting the Polish Labour Market, the demand for labour in the Silesia region will surpass the supply of workers in 2026 (Fig. 11). Because of demographic changes in Silesia – i.e., the declining population size and the ageing of the population – the labour supply in the region is expected to decrease by 400,000 workers by 2050, which will pose challenges for the development of the regional economy. Thus, the decreases in mining employment due to the phasing out of coal could help to ease the projected labour deficit, whereas delaying the process of decarbonisation and sustaining high employment in mining could aggravate labour shortages in other sectors.

To assess how important it is to retain laid-off miners in the labour force, we further analyze the projected supply of industry workers[14] in the Silesia region up to 2050. By 2030, the total supply of workers in the construction, manufacturing, energy, and logistics industries is projected to decrease by approximately 50,000 workers. These sectors require workers with skills similar to those of miners (World Bank, 2018b; Frankowski et al., 2021; Frankowski and Mazurkiewicz, 2020). Finally, the projected deficit in the supply of industrial workers is more than three times the number of miners at risk of losing their jobs due to the coal phase-out in the Polish Energy Policy scenario.[15] Releasing an additional supply of workers through reductions in mining employment may enable miners to find new jobs in construction and manufacturing, i.e., in sectors expected to face labour shortages in Silesia.

6. Discussions

In this section, we discuss policy recommendations to improve Poland's decarbonisation strategies and manage the projected labour market mismatches in hard coal mining. To provide the recommendations, we take stock both of the findings of our research and the previous findings of the socio-economic literature on the implications of the energy systems transition and destabilisation of the current energy regime (Kungl and Geels, 2018; Matschoss and Heiskanen, 2018) as the coal phase-out in Poland will reshape the socio-economic landscape in the region of Silesia (Geels and Schot, 2007), and create windows of opportunity for further transitions (Hölsgens et al., 2018).

[14] We define the industry workers according to the ISCO-08 classification. The list of occupations we consider in our analysis is in Appendix A4.
[15] Under the assumptions of the "Large increase in the CO_2 allowance prices" scenario of the Polish Energy Policy.

We suggest a hiring freeze policy should be implemented in the Polish hard coal mining sector starting in 2021. Such a freeze would significantly decrease the number of miners in need of support as this sector winds down its operations until the 2040s. Along with these changes, mines should consequently decrease their operating capacity to avoid deadweight loss investments. Intersectoral upskilling is crucial for filling the gap in engineering and technical supervision staff. A shortage of workers in these positions is likely to occur after 2030. Mining companies should manage the process of upskilling workers and include it in their decarbonisation strategies, as engineering and technical supervision workers are essential to the process of closing down mines. Moreover, vocational schools that provide mining-related education should respond to the needs of local labour markets by focusing on training electricians, plant and machine operators, and construction workers, rather than miners.

Policy instruments should be diversified to meet the needs of older and younger miners better. Older workers could be offered new jobs in coking coal mines or early retirement benefits. These instruments could mitigate the social consequences of the transition for older workers, who may find it difficult to change their occupations. Within active labour market policies, retraining or providing funds and advice for setting up and running new businesses should be prioritised. Reskilling programs are crucial for miners who are young enough to remain in the labour market but need new skills to work in sectors other than mining. The process of labour market transformation will require both public and private investments to ensure stable and decent jobs for reskilled workers. According to the government projections, the energy transition will provide 300,000 new workplaces (Ministry of Climate and Environment, 2021). However, the created jobs shall correspond, in terms of the required qualifications, to the skills of mining workers and the competitive advantages developed in the transformation regions. Construction and manufacturing industries have similar skills requirements, are developed enough to accommodate new workers, and are in line with mining workers' preferences (Tyrybon and Szczepański, 2004; Turek and Karbownik 2005; Kiewra et al. 2019). We have confirmed the relevance of these policy suggestions through 16 qualitative interviews with representatives of local labour market institutions in the mining subregions (Frankowski et al., 2021), who are the most experienced stakeholders in the mining workforce transition process.

The phase-out of hard coal mining should become a reference point for further stages of transition away from coal in Poland, especially for lignite basins, which have not been under the transformation process so far. Lignite mining companies are vertically integrated corporations that are large employers in the local labour markets, strongly influencing the economic character. The lignite phase-out in Poland will be concentrated in relatively small areas which are less diversified than the Silesia region where the hard-coal mining is located. Hence, the impact on local labour markets is likely to be stronger. The negative consequences of closing lignite mines may be mitigated with the proven measures: detailed recognition of workers' skills, targeted social support, and active labour market policy. The regional policy should be aimed at economic diversification and job creation based on the potential of local economies so far dominated by mining. The experience of isolated hard-coal hubs, such as Wałbrzych, also suggests that the policy response should also anticipate the coming changes rather than follow mine closures.

Our study may be further developed in four ways. First, a more detailed forecast of the demand for coal in the energy sector would improve our assumptions on labour supply and demand. Second, having access to worker-level data on miners' age, tenure, and education would allow for a more precise examination of potential skill gaps. Third, we excluded indirect and induced jobs from the analysis, as their measurement requires a separate study, beyond the scope of our paper. We recognise investigating the importance of the indirect effects of mine closures in the processes of coal-phase in Poland out as an emerging area of future studies. Finally, we based our findings on official documents and strategies introduced at the tipping point of the mining transformation in Poland, which are subject to ongoing political and social changes and may be revised in the future.

7. Conclusion

In this paper, we have studied the labour market dimension of the coal phase-out in Poland from 1990 to 2050. In the 1990s, the first stage of the coal phase-out overlapped with the economic and political transition, and structural shocks that affected mining, other industries, and the socio-economic situations of the population in Poland. These negative experiences still resonate in Poland and have led to concerns being raised that decarbonisation could lead to unemployment, poverty, and other socio-economic challenges.

Our study has three key findings.

First, we highlight the importance of multi-dimensional empirical analyzes of the socio-economic setting of transition pathways. In the Polish case, by applying the concept of branching points, we found that the labour market conditions for the coal phase-out have improved markedly since the late 2000s. In the 1990s and 2000s, workers who lost their coal mining jobs had few labour prospects, as industries that offered similar jobs (e.g., manufacturing, construction) were also struggling, and the labour supply and the numbers of jobseekers were increasing, especially among people with relatively low educational attainment. However, since the late 2000s, these conditions have changed as other industrial sectors have rebounded, the overall growth in the labour supply has slowed down due to demographic changes, and educational upgrading has improved the supply of skills. As a result, the labour market outlook for the future transition away from coal mining is much better than in the 1990s and early 2000s.

Second, the policy measures may alleviate the negative implications of the phase-out if the structural diversity is well recognized on the micro-level. In the Polish case, we found that the subregions that were dependent on coal in the 1990s have already transformed their labour market structures, and have been less reliant on coal mining since the mid-2000s. Additionally, we showed that in 2019, the hard coal mines were similar to each other in terms of their workers' age, educational, and gender structures, which should simplify the process of managing the transition. Finally, we note that the Polish mining subregions could benefit from their previous

experiences by using new dedicated funding, such as the Just Transition Fund, to mitigate the labour market consequences of decarbonisation. The policy should therefore anticipate and initiate the coming transition.

Third, clarity about the transition pathway is crucial for the paradigm shift. We concluded that the short-term horizon – i.e., up to 2030 – is decisive for the decarbonisation process in Poland and its labour market consequences. To achieve the targets set in the Polish Energy Policy, employment in hard coal mining has to decrease substantially by 2030, with as many as 14,000 jobs being reduced. We conclude by arguing that the decarbonisation targets in Poland should be more ambitious. We have provided evidence that it would be possible to phase out coal while also easing structural mismatches, enabling qualified workers to remain in the labour market, and securing the welfare of people working in mining-related industries.

Declaration of Competing Interest

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

Acknowledgments

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Appendix 1

A1.1. The formula for estimating the supply of labour in mining

We estimate the mining labour supply as follows:

$$S_t = \sum_{i=0}^{t} (S_t - R_t)$$

where S_t is the supply of labour in the year t, and R_t is the number of people reaching the retirement age in year t.

A1.2. The formula for estimating the demand for labour in mining

We estimate the demand for labour in mining as follows:

$$D_t = \pi_t (E_t + H_t + I_t)$$

Where D_t is the demand for labour in the year t, E_t is the demand for coal by the energy and heating sectors in the year t, H_t is the demand for coal by households in the year t, I_t is the demand for coal by industry in the year t, and π_t is the productivity of mining in the year t.

Appendix 2. The mining closure schedule

Year	Mine	Year	Mine
2021	Pokój	2040	Brzeszcze
	Wujek	2041	Mysłowice-Wesoła
2028	Bolesław Śmiały	2043	Rydułtowy
2029	Sośnica	2046	Marcel
2034	Bielszowice-Halemba	2049	Chwałowice
2035	Piast		Janina
2037	Ziemowit		Jankowice
2039	Murcki-Staszic		Sobieski
2040	Bobrek-Piekary		Bogdanka

Source: Own elaboration based on the agreement between government representatives and the Union Protest and Strike Committee of the Śląsko-Dąbrowski Region of September 2020.

Appendix 3

The structure of the educational attainment levels of the whole population, of the population aged 20-29, and of the population in the mining subregions; 1988, 2002, and 2011 (%)

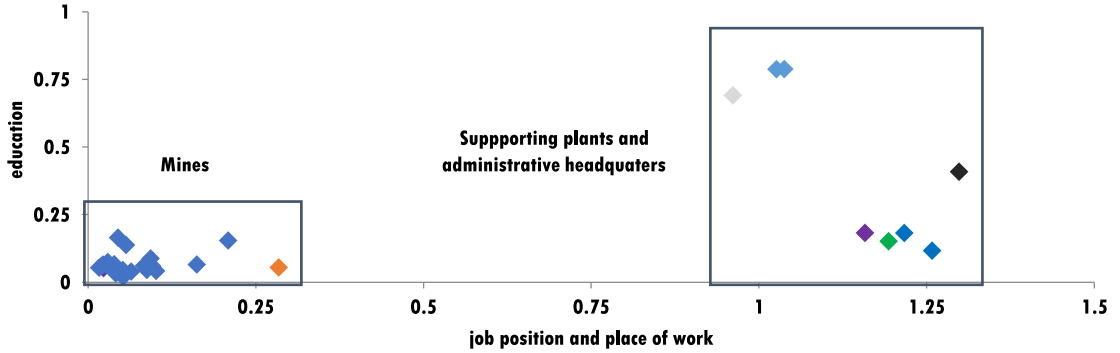

Fig. A3.1. The Euclidean distance between education and job position and place of work.
Source: Own elaboration based on the data obtained from mining companies.

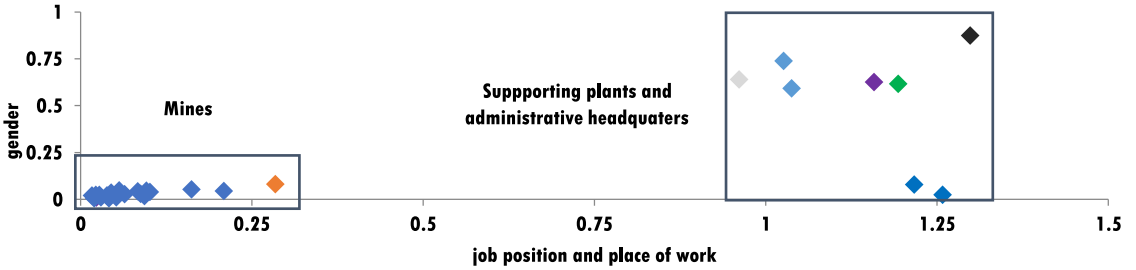

Fig. A3.2. The Euclidean distance between education and job position and place of work.
Source: Own elaboration based on the data obtained from mining companies.

Education level	Population			Population aged 20-29			Mining subregions		
	1988	2002	2011	1988	2002	2011	1988	2002	2011
Higher	7	11	20	5	14	30	6	10	17
Secondary	25	31	34	39	47	50	26	35	35
Vocational	24	25	26	41	28	15	32	30	28
Primary	44	33	20	15	10	5	36	26	20

Note: The data are from the national censuses for the years 1988 onwards.
Source: Own elaboration based on the Statistics Poland data (2021).

Appendix 4. The list of ISCO-8 industrial occupations related to mining used in the analysis

Code	Occupation	Code	Occupation
132	Manufacturing, mining, construction, and distribution managers	811	Mining and mineral processing plant operators
311	Physical and engineering science technicians	812	Metal processing and finishing plant operators
312	Mining, manufacturing, and construction supervisors	813	Chemical and photographic products plant and machine operators
313	Process control technicians	814	Rubber, plastic, and paper products machine operators
711	Building frame and related trades workers	815	Textile, fur, and leather products machine operators
712	Building finishers and related trades workers	816	Food and related products machine operators
713	Painters, building structure cleaners, and related trades workers	817	Wood processing and papermaking plant operators
721	Sheet and structural metal workers, moulders and welders, and related workers	818	Other stationary plant and machine operators
722	Blacksmiths, toolmakers, and related trades workers	831	Locomotive engine drivers and related workers
723	Machinery mechanics and repairers	832	Car, van, and motorcycle drivers
741	Electrical equipment installers and repairers	833	Heavy truck and bus drivers
742	Electronics and telecommunications installers and repairers	834	Mobile plant operators

Source: Own elaboration based on the ISCO-8 classification.

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