GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2024 Volume 40 Issue 4 Pages 147–159

DOI: 10.24425/gsm.2024.152721

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The effect of coal mine closures on worker migration in Poland: an input-output analysis

Introduction

The exhaustion of non-renewable resources, the intensifying climate crisis, and the spread of sustainable development principles have influenced a shift in energy policy priorities. In the past twenty years, there has been an increasing focus on maximising renewable energy use to lessen dependence on traditional energy sources and lower greenhouse gas emissions (Jonek-Kowalska 2022). In Poland, where nearly 80% of electricity is still generated from fossil fuels, the process of closing coal mines as part of a wide-ranging energy transition brings with it numerous economic and social challenges (Tokarski et al. 2021). Decisions to reduce coal mining are a response to global climate commitments and the drive to decarbonise the energy sector (Wojtkowska-Łodej 2014; Pepłowska 2021). Provisions for the gradual closure of hard coal mines in Poland are contained in the Social Agreement (Social Agreement 2021). This also results in the gradual extinction of jobs in mining regions, which creates the need to consider the fate of employees affected by this change.

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The migration of workers from closing coal mines is one of the key problems of the energy transition in Poland. In regions such as Silesia, where the mining industry plays a central role in the economy, the closure of mines may lead to significant difficulties in the labour market, both in terms of employment itself and in terms of structural opportunities to transform local economies. On the one hand, the reduction of thermal coal mining may contribute to an increase in internal migration, especially towards large urban centres offering greater employment prospects, while on the other hand, it requires intensive retraining of workers.

Studies conducted in projects such as ENTRANCES, or TANDEM, pay particular attention to the social consequences of these changes, especially in the context of unemployment, forced migration, and problems of workers' adaptation to new labour market conditions (Entrances 2024; Tandem 2024). Social aspects have been addressed in publications (Hubert et al. 2023; Kowalik et al. 2024). Nevertheless, the focus of this article is on an economic analysis that aims to determine the impact of mine closures on economic flows between sectors and on employment levels in mining regions.

To accurately analyse the impact of mine closures, input-output tables were used to track the linkages between economic sectors and measure indirect effects across industries. These data, compiled by the Central Statistical Office (CSO) in its publication *Input–output balance at current basic prices* (CSO 2019), provide a solid basis for macroeconomic analysis, allowing the identification of sectors most exposed to the negative effects of reduced thermal coal mining. Input-output tables also take into account sectors directly related to mining, the so-called peri–mining sectors; by analysing input–output flows, we can determine trade flows also between these sectors (Gawlik and Pepłowska 2017). Information on the input-output method (Leontief 1936, 1970, 1974, 1976; Leontief and Daniel 1972) and its possible use can be obtained from publications (Lach 2020; Lach et al. 2021). A detailed literature review on the use of the input-output method in the context of coal mining can be found in (Pepłowska and Olczak 2024). The use of the method in the context of mining was written about by (San Cristóbal and Biezma 2006).

To deepen this analysis, the input–output table was decomposed, separating branches such as the *Thermal Coal*, the *Coking Coal* and the *Lignite*, allowing for more precise tracking of economic flows in each sub-sector. The decomposition methodology is described in detail in a separate paper by the author of this study. The results of this analysis provide a better understanding of how reductions in thermal coal mining affect other sectors of the economy, allowing for a detailed analysis of potential adjustment pathways for workers who lose employment in the mining sector.

1. Migration of mining workers

Within the framework of this part of the article, an analysis has been carried out of the possible migration of workers (Migration Variant – WM) who will lose their jobs as a result of the closure of thermal coal mines in Poland (reduction of thermal coal output). The anal-

ysis is based on the assumed Variants for Reduction of Thermal Coal Extraction. The study proposes, presented below, options for reducing the supply of domestic thermal coal.

Reduction Variant WR25%

The 25% Reduction Variant (WR25%) is a variant reflecting the operation of the hard coal mining sector in Poland in 2015 after a reduction in the supply of domestic thermal coal by approximately 25%. A decrease in thermal coal production in Poland by approximately 25%.

Reduction Variant WR50%

The 50% Reduction Variant (WR50%) is a variant reflecting the operation of the hard coal mining sector in Poland in 2015 after a reduction in the supply of domestic thermal coal by approximately 50%.

Reduction Variant WR75%

The 75% Reduction Variant (WR75%) is a variant reflecting the operation of the hard coal mining sector in Poland in 2015 after a reduction in the supply of domestic thermal coal by approximately 75%. A decrease in thermal coal production in Poland by approximately 75%.

Reduction Variant WR100%

The 100% Reduction Variant (WR100%) is a variant reflecting the operation of the hard coal mining sector in Poland in 2015 in the absence of domestic thermal coal supply. No thermal coal mining in Poland.

As a result of the Reduction Variants carried out, a new domestic coal supply structure is assumed, which translates into a change in input–output flows in the structure of the country's economy and, consequently, in the structure of the Decomposed Input–Output Table (*TPMD*).

To carry out a detailed analysis of the impact of the migration of workers from the thermal coal sector on total production in other sectors, the re–deployment of miners from mines in liquidation, as part of the restructuring of the mining industry. An analysis and calculations were carried out for employment opportunities for miners in other sectors of the Polish economy. For this purpose, data on employment trends provided by the *Statistical Yearbook of Labour 2017* (data for 2015 CSO 2017).

To take a systematic approach to the analysis of migration opportunities, a sequence of activities (steps) was carried out separately for each branch of the economy included in the Decomposed Input–Output Table (*TPMD*). The following was carried out:

1. Started by using the employment data for each economic sector included in the input–output tables, this was taken as the basis for the calculations (CSO 2017).
2. A calculation was made of the number of people who would move from the *Thermal Coal* and the *Coking Coal* branches to other economic sectors (change of branches), included in the input–output table.

3. Calculation of the labour cost productivity index. Labour cost productivity, understood as the value of output produced in a given period by one employee (Hall et al. 1997; Wellbeing Poland 2023). The parameter was used as a measure of productivity for workers in the various branches of the economy, recalculated for each branch of the economy.
4. Determination of the average wage for each branch of the economy.
5. Determination of the increase in production volumes in the various branches (with the exception of the *Coal Branches*) resulting from the increase in the number of employees.

The analysis steps adopted were intended to provide a comprehensive perspective on changes in employment, productivity and wages, focused on the process of allocating carbon between economic sectors.

The number of employees who will move from the *Thermal Coal* and *Coking Coal* branches to another branch of the economy ($Lp_{wk,i}$) was calculated according to an established algorithm:

$$Lp_{wk,i} = \frac{Z_i}{\sum_i Z_i - Z_{wkib}} \cdot Lp^*_{wk} \tag{1}$$

- Z_i – number of persons employed in branch *i* in a given year, number of persons,
- $\Sigma_i Z_i$ – total employment in economic branches, number of people in a given year, number of persons,
- Z_{wkib} – number of persons employed in the *Coal Branches*, in a given year, number of persons,
- Lp^*_{wk} – the total number of employees moving from the *Thermal Coal* and *Coking Coal* branches to other industries after applying the Reduction and Substitution Variants, the number of persons, calculated as:

$$Lp^*_{wke} = \left((Z_{wke} - Z^*_{wke}) + (Z_{wkk} - Z^*_{wkk})\right) \cdot (1 - \text{pp}) \tag{2}$$

- Z_{wke} – number of people employed in the *Thermal Coal* branch, number of people in a given year, number of persons,
- Z^*_{wke} – number of people employed in the *Thermal Coal* branch after the introduction of the Reduction Variant (WR25%, WR50%, WR75%, WR100%), number of people in a given year, number of persons,
- Z_{wkk} – number of persons employed in the *Coking Coal* branch, number of persons in a given year, number of persons,
- Z^*_{wkk} – number of persons employed in the *Coking Coal* branch after the introduction of the Reduction Variant (WR25%, WR50%, WR75%, WR100%), number of persons in a given year, number of persons,
- *pp* – share of retirees, %.

According to Formulae (1 and 2), it should be noted that employees in the *Thermal Coal* and the *Coking Coal* branches migrate to branches other than the *Coal Branches* (which is meant the *Thermal Coal*, the *Coking Coal* and the *Lignite* branches).

The productivity of labour costs in branch i (PKP_i) was calculated according to an established algorithm:

$$PKP_i = \frac{X_i}{Z_i} \tag{1}$$

X_i – global consumption of products of branch i, thousand PLN,
Z_i – number of people employed in branch i in a given year, number of persons.

Analysis of the value of the average wage in branches based on data from the *Statistical Yearbook of Labour* (CSO 2017) were assigned to the relevant branches of the economy included in the Decomposed Input–Output Table.

The estimation of the increase in production volumes by sector (with the exception of *Coal Branches*) resulting from the increase in the number of employees consisted of two parts, viz:

- calculation of the change in the production value (WP_i, thousand PLN) caused by the increase in the number of employees (moving from the closing thermal coal mines) to other branches of the economy included in the Decomposed Input–Output Table:

$$WP_i = Lp_{wke,i} \cdot PKP_i \tag{4}$$

- designations as in formulas (1 and 3).
- the total value of production in branch i (CP_i) after the employment of additional workers for each branch of the economy included in the Decomposed Input–Output Table calculated according to the formula (excluding *Coal Branches*):

$$CP_i = X_i + WP_i \tag{5}$$

- designations as in formulas (3 and 4).

The average wages in the different economic sectors included in the input-output table taking into account the carbon allocation of the input-output table in 2015 are shown in the illustrative figure (Figure 1).

Data from the Central Statistical Office (CSO) shows that the level of unemployment in Poland is gradually decreasing, as can be seen in the graph (Figure 2).

Currently, the unemployment rate is relatively low, meaning that the number of unemployed people in the country is decreasing. Thus, there is a possibility that entrepreneurs are looking for new employees on the labour market. Therefore, there is a real opportunity to employ workers remaining in the labour market from restructured enterprises.

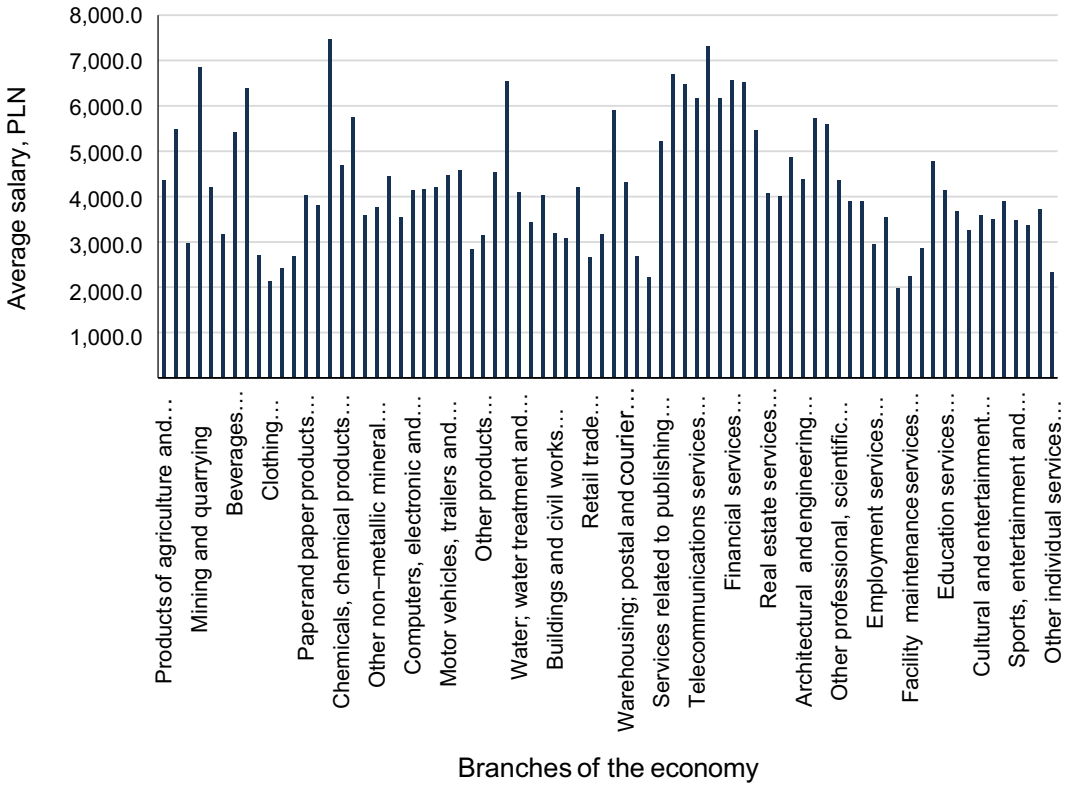

Fig. 1. Average wages by branches, 2015
Source: own compilation based on CSO (2017b)

Rys. 1. Przeciętne wynagrodzenia według branż, 2015 r.

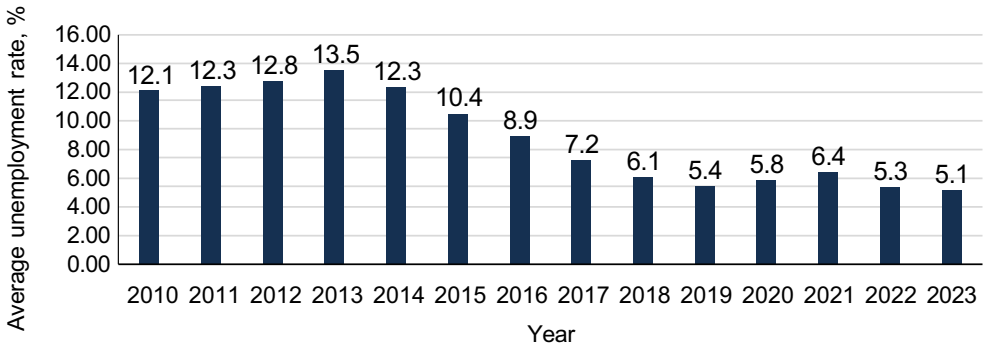

Fig. 2. Average unemployment rate in Poland (%)
Source: own elaboration based on CSO (2023e)

Rys. 2. Przeciętna stopa bezrobocia w Polsce (%)

As discussed, in the preceding section, each of the Reduction Variants leads to a reduction in thermal coal mining, resulting in a reduction in the number of people employed in the industry. As a result, redundant mining workers will seek new jobs, prompting the development of the Migration Option, which simulates the potential for *Coal Branch* workers to move to other industries.

Analysis of historical data revealed that some of those made redundant as a result of job cuts in the industry did not take up new employment and left the labour market. Therefore, the work assumed that 10 percent (*pp*) of the workers in the *Thermal Coal* and the *Coking Coal* branches who were made redundant as a result of the reduction in thermal coal output had left the labour market. In estimating the percentage of departing workers, various aspects were taken into account. One is the possibility of a lack of employment alternatives, and thus, having lost their jobs in the mining industry, some workers may find it difficult to find a new job, especially if their skills and experience are specific to this field. Another factor is the possibility of worsening employment conditions – if thermal coal mining is reduced, there may be worsened working conditions, a reduction in wages, or a reduction in available social benefits. This may cause some employees to decide not to look for a new job. There is also the possibility that some employees may decide to retire early or take other benefits, such as a pension, instead of continuing to work. Some workers may also decide to reorientate themselves in their jobs or take up education to acquire new skills adapted to other sectors of the economy.

This observation suggests that effective management of the migration process is key to mitigating the negative effects of downsizing in the mining sector. Consequently, measures must be taken to provide alternative employment opportunities for workers in this industry to support their transition to other industries.

2. The Migration Variants – the author's proposed approach

The paper decides to adopt a migration direction that will take into account two aspects – the number of people currently employed in a particular branch and the amount of loss that the branch will incur after the introduced Reduction Variants (WR25%, WR50%, WR75%, WR100%). Following the formula:

$$\Delta Z_i = f((WR, WS2), Z_i, WP_i) \tag{6}$$

- WR – Reduction Variants, possible reduction in domestic thermal coal production by 25%, 50%, 75 and 100%,
- $WS2$ – Substitution Variants, substitution of domestic thermal coal with imported thermal coal, imported natural gas and imported electricity,
- Z_i – number of persons employed in branch i in a given year, number of persons,
- WP_i – production value calculated according to formula (4), thousand PLN.

The work also proposed the introduction of a possible Substitution Variant (Substitution Model) for the substitution of domestic thermal coal with imported thermal coal, imported natural gas, and imported electricity, actions described in detail in a separate publication.

Following the principle that a greater number of people would move from the *Thermal Coal* and the *Coking Coal* industries to industries that currently employ a greater number of people relative to the other industries considered and that a greater number of people would move to industries that were less dependent on mining (lost less after applying the Reduction Variants). This principle is illustrated in Figure 3.

Fig. 3. Increase in the number of employees in the branches, thousands of persons
Source: own elaboration

Rys. 3. Wzrost liczby pracowników oddziałów, tysiące osób

The adoption of the principle that a larger number of people made redundant from the *Thermal Coal* and the *Coking Coal* branches move to sectors less dependent on mining and employing a larger number of workers is justified for several reasons. In the first place, industries less dependent on mining are more stable and less exposed to the structural changes associated with reductions in hard coal mining. As a result, work in these industries can be more resilient to economic changes, improving employment prospects for workers transitioning from the mining sector. Subsequently, sectors with more employees offer greater employment opportunities for those transitioning from the *Thermal Coal* and the *Coking Coal* industries. Introducing more workers into these sectors may be easier and more efficient in terms of absorbing large numbers of workers from the *Thermal Coal* and the *Coking Coal* branches. It is also worth noting that this approach has the potential to stimulate economic growth by diversifying employment and redirecting human resources to sectors with greater

growth potential. This is particularly important in the context of the structural transformation of the economy, where it is necessary to adapt to new market conditions and promote innovation and competitiveness. Thus, adopting the principle of redirecting more workers to industries less dependent on coal mining and employing more people seems logical from the point of view of both employment stability and economic development prospects.

The decision to choose the above direction of labour migration as the preferred way to deal with downsizing in the mining sector was therefore taken after taking into account a wide range of economic, social and structural factors that affect labour market dynamics and economic development prospects.

The article assumes that the migration of workers to other industries will result in increased production in those industries to which the workers will move. The above can be justified on the grounds that workers from the mining sector may bring with them specialised skills and experience that may be valuable in other industries. Their presence may increase the efficiency and productivity of production in the industries to which they will move. In addition, the availability of labour in these sectors may increase, which may lead to increased production to meet the growing demand for products and services. In addition, new workers may bring with them innovative ideas, which can lead to the development of new technologies in the industries to which they move. Increasing the number of workers in non–coal industries can contribute to the development of these sectors by increasing competition, increasing product and service diversity and improving quality. Together, all these factors can contribute to increased production in the economic sectors that absorb workers from the mining sector. However, the effectiveness of this process may depend on a number of factors, such as resource availability, infrastructure, or economic policy.

3. The Migration Variants – random sample

In addition, the author conducted additional simulations to explore potential worker migration scenarios. The Migration Variants – a random sample was additionally carried out. In order to test the possible range of changes in the distribution of results caused by the possibility of migration, a simulation of the random possibility of transition of mining employees was also performed.

Based on the Decomposed Input–Output Table, the value of Poland's GDP was recalculated based on the formula:

$$GDP = GP - IC + PT \tag{7}$$

where:
- GP – Global production, thausand PLN,
- IC – Intermediate consumption, thausand PLN,
- PT – Product taxes less product subsidies, thausand PLN.

Because the results of the migration model proposed by author in the paper show a small positive impact on a relatively large decline in GDP. Wanting to expand research to answer the question "What is the impact of the structure of migration on GDP?" an analysis of the simulation of random migration of workers using the Monte Carlo method was performed. Results indicated that there are such combinations of migration of mining workers to other industries that lead to an increase in the value of GDP and those that lead to a decrease in GDP values. In the case of random migration of workers, GDP could increase by an average of 0.218%. The simulation was performed on an empirical probability density distribution based on historical data, ten thousand draws were carried out, author's macro written in Visual Basic implemented in MS Excel. There was no limit to the number of employees who can move to a given branch (in an extreme scenario, there was a possibility that all employees will move to one branch).

By conducting this sampling of random worker transition possibilities, it was confirmed that the Migration Variants proposed by the author in Section 2 of the article (The Migration Variants – the author's proposed approach) are the more likely option and better reflect the real possibilities of worker migration.

Summary and final conclusions

To ensure energy security and the economic development of the country, changes in the raw materials market and plans to restructure the Polish coal mining industry are becoming particularly important.

Measures aimed at reducing the extraction of thermal coal in the country, which result from a consistent climate and energy policy aimed at reducing the negative impact of fossil fuel combustion on the environment, contribute to changing the structure of the fuel mix and, as a result, to the closure of hard coal mines. Considering the possibility of labour migration in the context of structural change in mining is an extremely complex issue that can be approached from multiple angles. Some various options and strategies can be considered, taking into account both social and economic aspects.

There are many opportunities for migration, and consequently: labour migration enables the redirection of human resources from the mining sector to other sectors of the economy that may be more dynamic and forward–looking. This is important because of the flexibility of the labour market and the ability to adapt to structural changes. In addition, labour migration can contribute to the diversification of professional skills and competences, which can increase the resilience of workers to future labour market changes and improve their competitiveness. The migration process can stimulate the development of other sectors of the economy by bringing in new talent and experience, which can contribute to economic growth and job creation.

In the case of random labour migration, GDP can increase by an average of 0.218%, meaning that migration can have a positive impact on improving GDP, positively affecting

the national economy. In contrast, there are also configurations in which the impact is negative. This conclusion may be a suggestion for national transition policy makers towards the possibility of creating new jobs for mining workers after the closure of Polish coal mines.

With regard to the analysis of the transition of workers from the mining industry to others, the author's model was performed. Assumptions were made about the number of retirements (10%) and the fact that migration would be towards branches that were less affected by the action of reducing thermal coal mining. By doing the calculations, in stages, it is concluded that migration affects GDP and, in the case of the above assumptions, reduces the decrease in GDP that is caused by the closure of thermal coal mines, however, the magnitude of the impact is small. It should be noted that various other combinations of labour migration have a relatively high impact on GDP. For a 0.62% decrease in GDP for the scenario with the WR100% Reduction Variant, the spread of results for different Migration Variants chosen at random can reach 0.218% of the increase in GDP.

The energy transition, including the move away from thermal coal mining in Poland, is causing various changes, including economic ones.

The results presented in this paper and their proper interpretation may be relevant to those responsible for shaping national energy policy.

This work was carried out as part of the statutory activity of the Mineral and Energy Economy Research Institute of the Polish Academy of Sciences.

The Authors have no conflicts of interest to declare.

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THE EFFECT OF COAL MINE CLOSURES ON WORKER MIGRATION IN POLAND: AN INPUT-OUTPUT ANALYSIS

Keywords

hard coal, decarbonisation, energy transition, workers migration, coal mine closings

Abstract

Closing coal mines in Poland is an important part of the energy transition aimed at reducing greenhouse gas emissions and meeting climate commitments. These decisions are particularly important in mining regions such as Silesia, where the mining industry is the main pillar of the economy. Given the gradual closure of mines and the reduction of employment in the mining sector, there is a need to an-

alyse the migration of workers and their potential adaptation to the labour market. This paper aims to examine the impact of mine closures on the employment structure of the national economy using the input-output method. The analysis includes a decomposition of input-output tables (TPMD), in which branches such as thermal coal, coking coal, and lignite were distinguished. This has made it possible to precisely track economic flows between subsectors of the economy and identify which sectors are most vulnerable to the negative effects of reduced coal mining in Poland. The analysis also shows how a change in coal mining may affect related sectors such as energy, transport, and steel, increasing the need for structural adjustments. In particular, the article focuses on possible scenarios for the migration of workers from the closing mines and their re-deployment. Various coal reduction (WR) variants are considered, including WR25%, WR50%, WR75%, and WR100%, reflecting scenarios of declining domestic production. The paper also considers the possible substitution of domestic coal with imported raw materials (WS). The article concludes by identifying the most important conclusions.

WPŁYW ZAMYKANIA KOPALŃ WĘGLA KAMIENNEGO ENERGETYCZNEGO W POLSCE NA MIGRACJĘ PRACOWNIKÓW W GOSPODARCE Z WYKORZYSTANIEM METODY PRZEPŁYWY MIĘDZYGAŁĘZIOWYCH

Słowa kluczowe

węgiel kamienny, dekarbonizacja, transformacja energetyczna,
migracja pracowników, zamykanie kopalń wegla

Streszczenie

Proces zamykania kopalń węgla kamiennego w Polsce stanowi istotny element transformacji energetycznej, której celem jest ograniczenie emisji gazów cieplarnianych i realizacja zobowiązań klimatycznych. Decyzje te są szczególnie ważne w regionach górniczych, takich jak Śląsk, gdzie przemysł wydobywczy stanowi główny filar gospodarki. W obliczu stopniowego wygaszania kopalń i redukcji zatrudnienia w sektorze górniczym pojawia się konieczność analizy migracji pracowników oraz ich potencjalnej adaptacji na rynku pracy. Celem artykułu jest zbadanie wpływu zamykania kopalń na strukturę zatrudnienia w krajowej gospodarce przy wykorzystaniu metody przepływów międzygałęziowych. Przeprowadzona analiza obejmuje dekompozycję tablic przepływów międzygałęziowych (TPMD), w której wyróżniono gałęzie takie jak węgiel kamienny energetyczny, koksowy oraz brunatny. Umożliwiło to precyzyjne śledzenie przepływów ekonomicznych między podsektorami gospodarki i określenie, które sektory są najbardziej narażone na negatywne skutki zmniejszenia wydobycia węgla w Polsce. Analiza pokazuje także, jak zmiana wydobycia węgla może wpłynąć na powiązane sektory, takie jak energetyka, transport i przemysł stalowy, zwiększając potrzebę dostosowań strukturalnych. W szczególności artykuł koncentruje się na możliwych scenariuszach migracji pracowników z zamykanych kopalń oraz ich przebranżowienia. Rozważane są różne warianty redukcji wydobycia węgla (WR), w tym WR25%, WR50%, WR75% oraz WR100%, odzwierciedlające scenariusze spadku krajowej produkcji. W artykule uwzględniono również możliwą substytucję krajowego węgla surowcami importowanymi (WS). Artykuł zakończony jest wskazaniem najważniejszych wniosków.