



Intersectoral Linkages in Kazakhstan's Energy Sector: A Comparative Leontief Analysis

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Abstract

The intensive utilization of production resources in Kazakhstan's energy sector and the increase in interdependence between industries make it particularly important to assess the stability and efficiency of the economic system structure. In particular, the coal, petroleum, natural gas and electric power industries constitute the main energy base of the national economy and reflect the interconnection between industries. Therefore, the analysis of intersectoral relationships and structural transformation in the energy sector has become the main direction of modern economic research. In addition, changes in the flow of resources within the energy system directly affect the long-term stability and efficiency of the economy. The purpose of this research is to use a comparative Leontief input-output analysis to examine changes in intersectoral relationships within Kazakhstan's energy sector and evaluate structural transformations from 2020 to 2024. The methodological basis of this research is a comparative input-output analysis based on the Leontief inter-industry equilibrium framework. This study uses the official statistics of the Republic of Kazakhstan for 2020-2024, including production indicators of the energy sector and intersectoral intermediate consumption data. The analysis is based on a reduced four-sector input-output framework representing the main energy industries of Kazakhstan (coal, oil, natural gas, and electricity), rather than the complete national input-output table. In addition, the intermediate consumption matrix (Z_t), the technical coefficient matrix (A_t), the Leontief inverse matrix $((I - A_t)^{-1})$, and backward linkage (BL) and forward linkage (FL) indicators were calculated. The findings reveal that moderate structural adjustments occurred within Kazakhstan's energy system during 2020-2024. The electricity sector exhibited the highest multiplier effect, confirming its role as the core sector of the system. The obtained results characterize the changing production interdependencies within the energy system, the restructuring of intersectoral linkages, and the systemic evolution of the energy sector.

KEYWORDS

Energy, Energy Economy, Energy Sector, Sectoral Dependence, Resource Flow, Production Structure, Intersectoral Relationship, Leontief Model

1 | INTRODUCTION

At present, the depletion of natural resources, the growth of industrial waste, and climate change have become among the major environmental and economic challenges threatening the sustainable development of the global economy. At the international level, these challenges require new analytical and policy approaches to improve resource efficiency, reduce carbon emissions, and manage industrial waste. In particular, the energy sector is considered one of the most resource-intensive areas of economic activity and a major contributor to environmental pressure (Karatayev et al., 2016). The industrialization of the global economy has led to increasing energy consumption, the accumulation of industrial waste, and the expansion of harmful atmospheric emissions (Steffen et al., 2015). As a result, many countries are seeking new development models that ensure resource efficiency and environmental sustainability. In this context, growing attention has been devoted to the concept of the circular economy (Kirchherr et al., 2017).

The energy sector is of strategic significance in Kazakhstan's economy and is one of the main engines of the country's industrial development. Coal, oil, natural gas, and electricity constitute the core of Kazakhstan's energy system and generate substantial export revenue. However, the sector is characterized by high resource intensity, substantial industrial waste generation, and increasing environmental impacts.

In addition to contributing to industrial production and economic growth, Kazakhstan's energy sector plays an important social role, supporting employment, household welfare, and regional development. Structural changes in the energy system can affect labor demand in related sectors, the reliability of energy supply, and the effectiveness of public investments. In addition, strengthening intersectoral linkages can help maintain national energy security and provide a more stable basis for implementing long-term economic and social policies. Therefore, analyzing the structural transformation of the energy sector is important not only for understanding its economic significance but also for assessing its implications for social development and public policy.

Until recently, economic development was mainly based on traditional linear economic principles. This model is characterized by a linear resource flow based on extraction, production, consumption, and disposal, which has contributed to resource depletion, increasing waste generation, and environmental degradation (Korhonen et al., 2018). International experience has shown that the linear economic model is insufficient to ensure long-term sustainable development. Therefore, in recent years, the concept of the circular economy has attracted widespread attention in the academic literature and public policy fields.

Intersectoral analysis methods have been widely used to comprehensively assess the environmental and economic relationships within the energy sector. The Leontief input-output framework provides a systematic approach to analysing production flows among different sectors of the economy (Leontief, 1986). It has also been widely applied to evaluate structural changes, intersectoral linkages, and multiplier effects across different time periods.

In this study, a comparative input-output analysis based on the Leontief framework is employed to examine the structural transformation of Kazakhstan's energy sector. Specifically, for Kazakhstan's energy sector from 2020 to 2024, the technical coefficient matrix (A_t), intermediate consumption matrix (Z_t), total output vector (X_t) and Leontief inverse matrix $((I - A_t)^{-1})$ are calculated, and changes in these matrices are analysed.

The main advantage of this method is that it captures not only direct production linkages but also indirect multiplier effects. This allows us to determine the degree of structural dependence between the energy sectors, changes in intersectoral relationships, and the direction of economic structural adjustment. In addition, backward linkage (BL) and forward linkage (FL) indicators are used to identify the systemic role of each sector as a major user of inputs or supplier of outputs.

In Kazakhstan, the evolution of the energy sector's production structure, changes in intersectoral dependence, and the structural transformation of the energy system have not yet been comprehensively studied. In particular, studies applying comparative input-output analysis to examine structural changes and intersectoral relationships in Kazakhstan's energy sector remain limited.

The identified research gaps are addressed in this study, and several key contributions are made. First, the intersectoral structure of Kazakhstan's energy sector is analysed using comparative Leontief input-output analysis. Second, structural changes during 2020-2024 are quantified using the technical coefficient matrix and the Leontief inverse matrix. Third, the systemic roles of energy sectors are identified using backward and forward linkage indicators, thereby characterizing their relative systemic importance within the energy sector. Fourth, the results enable interpretation of changes in the energy sector's multiplier structure.

The study aims to assess changes in intersectoral linkages within Kazakhstan's energy sector during 2020–2024 using comparative Leontief input–output analysis. To achieve this objective, the following research tasks are formulated:

- (1) constructs annual four-sector intermediate consumption and technical coefficient matrices;
- (2) calculates and compares the corresponding Leontief inverse matrices for 2020–2024;
- (3) assesses backward and forward linkages within Kazakhstan's energy subsystem.

2 | LITERATURE REVIEW

The structural transformation of energy systems has attracted growing attention because of its implications for economic efficiency, employment, industrial competitiveness, regional development, energy security, and macroeconomic stability. Changes in intersectoral production linkages may influence employment dynamics, industrial competitiveness, regional development, energy security, and overall macroeconomic stability. Therefore, the assessment of structural changes within energy systems has become an important research direction in contemporary economic studies (IEA, 2024; ILO, 2023). Understanding these transformations re-

quires analytical approaches that capture complex relationships among economic sectors, resource flows, and environmental impacts.

The theory of the circular economy has, in recent years, become one of the key directions within the concept of sustainable development and is increasingly regarded as a new economic model based on the efficient use of resources and the reduction of industrial waste (Geissdoerfer et al., 2017; Kirchherr et al., 2017). While traditional linear economic systems are based on the «take-use-dispose» principle, the goal of a circular economy is to ensure environmental sustainability through the reuse, recycling, and reintegration of recycled materials into the production cycle (Korhonen et al., 2018). In this regard, a comprehensive assessment of industrial waste generation and resource flows is particularly important in scientific research. Because the energy sector is one of the most resource-intensive industries and exerts significant environmental pressure, modeling waste flows in this sector has become a major research area in the circular economy (Karatayev et al., 2016).

The input-output framework developed by Wassily Leontief provides a fundamental analytical approach for examining intersectoral relationships within an economy (Leontief, 1986). The framework describes the flow of intermediate inputs among sectors and enables identification of the direct and indirect production requirements associated with changes in final demand. The technical coefficient matrix represents the direct input requirements of each sector, while the Leontief inverse captures the total production effects generated throughout the economy. Consequently, Leontief input-output analysis can be used to assess intersectoral dependencies, multiplier effects, and the relative importance of individual sectors within a production system (Miller & Blair, 2009). These analytical capabilities have made the Leontief framework an important tool for examining structural changes and linkages across economic sectors. Building on this framework, researchers have also developed extended input-output models incorporating environmental variables such as energy consumption, greenhouse gas emissions, and resource use, thereby broadening the application of input-output analysis to sustainability and environmental assessment.

With the development of Input-Output Analysis, the comparative application of the Leontief framework has become an important method for examining changes in the structure of production systems over time. By comparing input-output tables across different periods, researchers can identify changes in technical coefficients, intermediate input requirements, production structures, and intersectoral relationships. For example, Weber (2009) employed Input-Output Analysis and decomposition analysis to examine changes in energy use and structural transformation in the US economy between 1997 and 2002, demonstrating the importance of changes in the production structure for understanding energy demand. Similarly, Han and Lakshmanan (1994) applied energy input-output analysis to examine structural changes and energy consumption in the Japanese economy between 1975 and 1985. More recently, Nieto et al. (2022) analyzed time-series input-output tables to assess the relationship between energy intensity and changes in the process coefficient matrix, emphasizing the importance of input-output struc-

tures in analyzing long-term structural transformation. Therefore, comparative Input-Output Analysis can be used to assess changes in production technologies, intersectoral interdependencies, and the direct and indirect effects captured by the Leontief inverse matrix. This approach is particularly important for research in the energy sector because changes in the structure of production and energy demand can alter the systemic role of different subsectors within the economy as a whole.

Donati et al. (2020) developed an environmentally extended input-output framework for modeling circular economy strategies, including resource efficiency and product lifetime extension. Their study demonstrated how input-output models can be extended to assess the environmental and socio-economic effects of circular economy intervention.

Wiebe et al. (2019) applied a multi-regional input-output (MRIO) model to compare a business-as-usual scenario with a circular economy scenario, examining the economy-wide, environmental, and employment effects of increased recycling, material efficiency, repair, and reuse. Their results demonstrated the potential of MRIO analysis to assess the broader impacts of circular economy strategies.

While previous studies have extensively applied input-output models to analyse environmental impacts, resource efficiency, and circular economy strategies, limited attention has been given to the structural transformation of Kazakhstan's energy sector through comparative Leontief analysis. In particular, changes in intersectoral dependencies, production linkages, and multiplier effects among key energy subsectors remain insufficiently explored. Therefore, this study addresses this research gap by applying comparative input-output analysis to evaluate structural changes in Kazakhstan's energy sector during 2020-2024.

Recent developments in intersectoral analysis and modeling of circular economies further expand the theoretical and methodological foundations of this study. For example, Su and Ang (2010) used an intersectoral analysis method to examine carbon emissions in international trade, focusing on the impact of industrial structure on the environment.

Tukker and Dietzenbacher (2013) conducted a comprehensive review of sustainability analysis based on intersectoral balance, emphasizing the importance of linking economic structure to environmental pressures in policy assessments. Lenzen et al. (2013) proposed a high-precision multi-regional input-output database that tracks energy consumption and emissions across the global supply chain in detail, significantly improving the accuracy of environmental accounting. Zeng et al. (2017) used input-output methods to study the development of China's circular economy and identified key issues, such as waste generation and resource inefficiency, in specific industries.

Dietzenbacher et al. (2015) extended the structural decomposition method to input-output models, enabling them to analyze how changes in production structure and demand composition affect economic performance over time. Hertwich and Wood (2018) used the multi-regional input-output model (MRIO) to analyze the impact of consumption on the global environment, emphasizing the importance of the final demand structure in determining resource utilization and

emissions. Finally, Owen et al. (2018) analyzed the role of input-output analysis in energy transition research, emphasizing its usefulness in evaluating the structural aspects of the transition to a low-carbon economy. However, existing studies mainly focus on global economies or environmental assessments, while empirical evidence on structural transformations within Kazakhstan's energy sector remains limited. This study contributes to the literature by applying comparative Leontief input-output analysis to identify changes in sectoral relationships and multiplier effects during 2020–2024.

Despite the extensive application of input-output models to examine structural change, intersectoral linkages, energy use, and environmental impacts, empirical evidence on the structural transformation of Kazakhstan's energy sector remains limited. Existing studies on energy and input-output relationships have predominantly focused on environmental impacts, resource use, energy efficiency, or economy-wide assessments. At the same time, comparatively little attention has been given to changes in intersectoral production linkages within Kazakhstan's energy sector over time. In particular, the comparative analysis of technical coefficient matrices, Leontief inverse matrices, and backward and forward linkages across different periods remains insufficiently explored.

Although input–output methods have been widely applied to analyze energy use, emissions, and structural change, evidence on year-to-year changes in production linkages among Kazakhstan's coal, oil, natural gas, and electricity sectors remains limited. This study addresses this gap by comparing annual technical coefficient and Leontief inverse matrices and assessing absolute backward and forward linkage measures for 2020–2024.

3 | RESEARCH METHODS

This study uses the Leontief input-output model and comparative input-output analysis to evaluate structural changes in intersectoral linkages in Kazakhstan's energy sector. This approach enables analysis of production interdependence, resource flows, and multiplier effects across various sectors of the economy by comparing annual input-output tables.

The methodological basis of this research is the classic input-output equilibrium model proposed by Wassily Leontief. The model describes intersectoral production relationships among economic sectors in matrix form and can evaluate product flows across sectors. The main equations of the classic input-output equilibrium model are as follows (1):

$$X = AX + Y \quad (1)$$

where:

X – vector of total economic output;

A – matrix of intersectoral technical coefficients;

Y – vector of final demand.

This model shows that a portion of output is used for intermediate consumption in other sectors, while the remaining share is directed towards final consumption.

The technical coefficient matrix describes the technological interdependence between sectors and determines the degree to which each sector depends on the products of other sectors. By transforming equation (1), we obtain the standard Leontief form:

$$X = (I - A)^{-1} Y \quad (2)$$

where:

I – identity matrix;

$(I - A)^{-1}$ – Leontief inverse matrix, representing the total multiplicative effect of direct and indirect production relationships.

The Leontief inverse matrix reflects the full impact of direct and indirect interdependencies in production within the economy. Each element of the matrix indicates the extent to which a change in final demand in a particular sector influences the total level of economic output.

To examine structural changes in Kazakhstan's energy sector, separate technical coefficient matrices were constructed for each year of the study period (2020–2024). Based on these matrices, the corresponding Leontief inverse matrices were constructed and analyzed to compare changes in intersectoral production relationships over time.

The gross output vector X_t for each year was constructed from the gross output of the four energy sectors: coal production, oil extraction, natural gas production, and electric power generation. The corresponding gross output values are presented in Table 1 in the Results section. For each year t , the gross output vector was defined as (3):

$$X_t = \begin{bmatrix} x_1(t) \\ x_2(t) \\ x_3(t) \\ x_4(t) \end{bmatrix} \quad (3)$$

where:

x_1 – coal production;

x_2 – oil production;

x_3 – natural gas production;

x_4 – electric power generation.

The intermediate consumption matrix for year (t) was defined as Z_t , where represents the monetary value of the output supplied by sector (i) and used as an intermediate input by sector (j) . The technical coefficient matrix was calculated as (4) and (5):

$$A_t = Z_t \overline{X_t}^{-1} \quad (4)$$

$$a_{ij} = \frac{z_{ij}}{x_j} \quad (5)$$

where:

A_t – technical coefficient matrix;

Z_t – intermediate consumption matrix;

$\bar{X}_t^{-1}$ – inverse diagonal matrix of gross output;

z_{ij} – output of sector (i) used in the production process of sector (j);

x_j – gross output of sector (j).

The technical coefficient matrices (A_t) were constructed separately for each year from 2020 to 2024 using official input-output tables published by the Bureau of National Statistics of the Republic of Kazakhstan. The gross output vectors (X_t) and intermediate consumption matrices (Z_t) were obtained directly from the official input-output tables for the corresponding years. Based on these data, the technical coefficient matrices were calculated according to Equation (4), and the corresponding Leontief inverse matrices were subsequently derived for each year to enable a comparative input-output analysis of changes in intersectoral production relationships over time.

The analysis is focused on four major sectors of Kazakhstan's energy industry: coal production; oil extraction; natural gas production; electric power generation. For each year during the period 2020-2024, separate gross output vectors (X_t), intermediate consumption matrices (Z_t), technical coefficient matrices (A_t), and Leontief inverse matrices ($(I - A_t)^{-1}$) were calculated and compared.

In addition, backward linkage (BL) and forward linkage (FL) indicators were applied to evaluate the systemic role of the energy sectors. The backward linkage indicator describes the extent to which a sector draws resources from other sectors. In contrast, forward linkage indicator reflects the extent to which that sector's products are used in the broader economy.

The BL and FL metrics are determined by summing the corresponding columns and rows of the inverse Leontief matrix (6) and (7):

$$BL_j = \sum_i l_{ij} \quad (6)$$

$$FL_i = \sum_j l_{ij} \quad (7)$$

where:

l_{ij} – represents the elements of the Leontief inverse matrix.

The measures were calculated as simple column and row sums without Rasmussen–Hirschman normalization. Consequently, they are interpreted as absolute linkage measures rather than normalized linkage indices. They are used to compare the relative positions of the four sectors and their changes over time, but not to classify sectors as “key sectors” based on a normalized threshold.

This procedure provides a consistent basis for comparing changes in production interdependence and linkage structures within Kazakhstan's four-sector energy subsystem during 2020–2024.

4 | RESULTS

The empirical analysis employed a reduced four-sector input–output model comprising coal production, oil extraction, natural gas production, and electricity generation. Accordingly, the derived Leontief multipliers and linkage measures capture structural relationships within the analyzed energy subsystem rather than within Kazakhstan’s economy as a whole.

The calculations based on the comparative Leontief input-output model indicate that the energy sector in Kazakhstan underwent significant structural changes during 2020-2024. The numerical data used in the analysis were compiled from official statistical sources, and changes in intersectoral relationships were assessed by comparing annual technical coefficient matrices. The technical coefficients did not exhibit a uniform downward trend. Instead, they showed considerable structural variation across sectors, with the most pronounced changes observed after 2022.

Table 1 presents the gross output values used as the empirical basis for constructing the annual input-output matrices.

Table 1. Gross output of the selected energy sectors in Kazakhstan for 2020–2024, in KZT thousand

Indicator	2020	2021	2022	2023	2024
Coal production	570 469 600	647 156 633	977 766 378	874 778 826	843 722 600
Oil production	8 168 627 300	13 179 766 639	19 278 363 928	16 037 269 765	16 382 767 200
Natural gas production	418 313 500	428 895 731	624 088 747	460 542 968	455 455 400
Electric power generation	1 464 707 199	1 883 597 343	2 311 864 715	2 385 422 844	2 660 278 399

Note: compiled by the authors

The data show substantial differences in production dynamics across the four energy sectors. Oil extraction accounted for the largest monetary gross output throughout the study period. Electricity generation was the only analyzed sector whose gross output increased every year, rising from KZT 1.465 trillion in 2020 to KZT 2.660 trillion in 2024, or by 81.6%. The monetary gross output of coal, oil, and natural gas reached its highest level in 2022. Between 2022 and 2024, it subsequently decreased by 13.7% for coal, 15.0% for oil, and 27.0% for natural gas. These changes in sectoral output provide the empirical basis for assessing changes in intersectoral production relationships during 2020-2024.

The selected intermediate consumption linkages for Kazakhstan’s energy subsystem for 2020–2024 are presented in Table 2.

The results demonstrate substantial changes in the intensity of intersectoral linkages during 2020-2024. Coal-to-electricity flows remained among the largest intermediate linkages throughout the period, although their magnitude declined after 2022. Electricity-to-oil and electricity-to-gas linkages also varied considerably across the study period. In contrast, electricity-to-electricity intermediate consumption increased sharply in 2023-2024, indicating a substantial strengthening of internal production linkages within the electricity sector. Overall, the observed

changes indicate a transformation in the structure and intensity of intersectoral relationships within Kazakhstan's energy subsystem.

Table 2. Selected intermediate consumption linkages in Kazakhstan's energy subsystem for 2020- 2024

Producer sector / Con- suming sector	2020	2021	2022	2023	2024
Coal→ Coal	3 884 149	3 717 841	8 423 917	21 280 997	12 801 819
Coal→ Oil	20 167	43 488	78 961	5 235	5 118
Coal→ Gas	-	-	-	240	245
Coal→ Electricity	128 988 430	139 096 529	221 446 570	173 073 419	122 022 945
Oil→ Coal	-	-	-	-	-
Oil→ Gas	-	-	-	-	-
Oil→ Oil	28 686 317	95 892 259	35 934 857	66 665 097	53 609 340
Oil→ Electricity	99 423	293 025	6 455	-	-
Gas→ Coal	-	-	-	-	-
Gas→ Oil	11 383 308	38 184 571	103 784 346	5 804 764	14 295 386
Gas→ Electricity	5 071 493	8 497 562	16 889 388	11 733 754	23 676 593
Electricity→ Coal	18 004 686	17 916 593	46 940 390	2 809 631	1 430 237
Electricity→Oil	54 873 385	107 089 841	203 773 854	75 165 787	60 791 513
Electricity→Gas	21 171 446	28 444 091	55 724 904	1 817 000	1 571 411
Electricity→Electricity	23 504 117	28 662 018	48 709 185	301 341 967	287 405 773

Note: compiled by the authors

The technical coefficient matrix (A_t) describes the technological structure of production within Kazakhstan's energy subsystem by indicating the amount of input required from each sector to produce one unit of output in another sector. The technical coefficient matrices for 2020-2024 were calculated based on the corresponding intermediate consumption and total output data.

Figure 1 illustrates the changes in the technical coefficient matrix (A_t) for the period 2020-2024 and shows how intersectoral production linkages evolved over the study period, reflecting changes in technological dependence among the energy sectors.

The results shown in Figure 1 indicate that most technical coefficients remained relatively low throughout the study period, while several coefficients demonstrated substantial structural variation. In particular, the coefficients (a14), (a41), (a43), and (a44) exhibited the most pronounced changes, indicating shifts in the intensity of key production linkages within Kazakhstan's energy subsystem.

The a14 coefficient was relatively high during 2020-2022 and increased to 0,09582 in 2022. This indicates a strengthening dependence of sector 4 (electric power generation) on intermediate inputs supplied by the coal sector (coal industry). However, the sharp decline in 2023-2024 reflects a structural change in production or an ongoing technological adjustment process. The reduction of the coefficient to 0,045868 in 2024 suggests a weakening of the previous production

linkage between these sectors. The a_{41} coefficient also increased until 2022 and then declined significantly. This reflects a reduced share of sector 4 resources used in sector 1 production. The post-2023 decline may indicate a restructuring of intersectoral material flows. The coefficient rose from 0.02106 in 2022 to 0.12633 in 2023 and remained comparatively high at 0.10803 in 2024. This result indicates a substantial increase in the internal input intensity of the electricity sector.

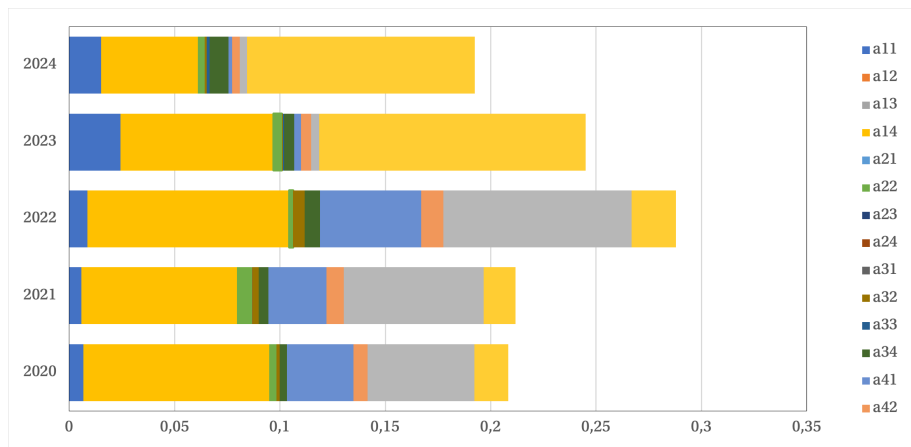


Figure 1. Technical coefficients of the energy subsystem for 2020–2024

Because these coefficients are calculated from monetary input–output tables, their changes may reflect shifts in input structure, relative prices, or statistical classification. Therefore, they should not be attributed exclusively to technological restructuring without additional decomposition analysis. Conversely, the coefficients a_{12} , a_{13} , a_{21} , a_{23} , a_{24} , and a_{31} remained zero or close to zero throughout the study period. This indicates that the corresponding direct input requirements between these specific sector pairs were negligible within the four-sector energy subsystem. However, it does not imply that the overall intersectoral relationships of these sectors were weak.

Overall, the annual technical coefficient matrices reveal non-uniform changes in the structure of Kazakhstan's energy subsystem during 2020–2024. Although some intersectoral linkages weakened, dependence among the energy sectors increased in several areas, reflecting the redistribution of resource flows and changes in the production structure.

Based on the annual technical coefficient matrices, the corresponding Leontief inverse matrices were calculated as $(I - A_t)^{-1}$ were obtained for 2020–2024. The resulting output multipliers are presented in Figure 2.

The results show that the electricity sector recorded the highest output multiplier throughout the study period. Its diagonal element was 1,019393 in 2020, increased to 1,027066 in 2022, and rose sharply to 1,144935 in 2023. Although it slightly declined to 1,121163 in 2024, it remained the highest among all sectors, indicating that the electricity sector functions as the core sector of Kazakhstan's energy system. This result suggests that the electricity sector (sector 4, i.e., element

4.4) is not only an energy producer but also a key sector that influences the production structures and intersectoral linkages of the other energy sectors (coal, oil, and gas). The sharp increase observed in 2023 indicates a strengthening of indirect production relationships and a higher degree of structural interdependence within the energy system. The multiplier coefficient of the coal industry (industry 1, that is, element 1.1) is relatively stable, between 1,009729 and 1,025217, indicating that its systemic impact is low but stable. This reflects coal's status as a key economic resource, although its structural impact remains weaker than in power generation.

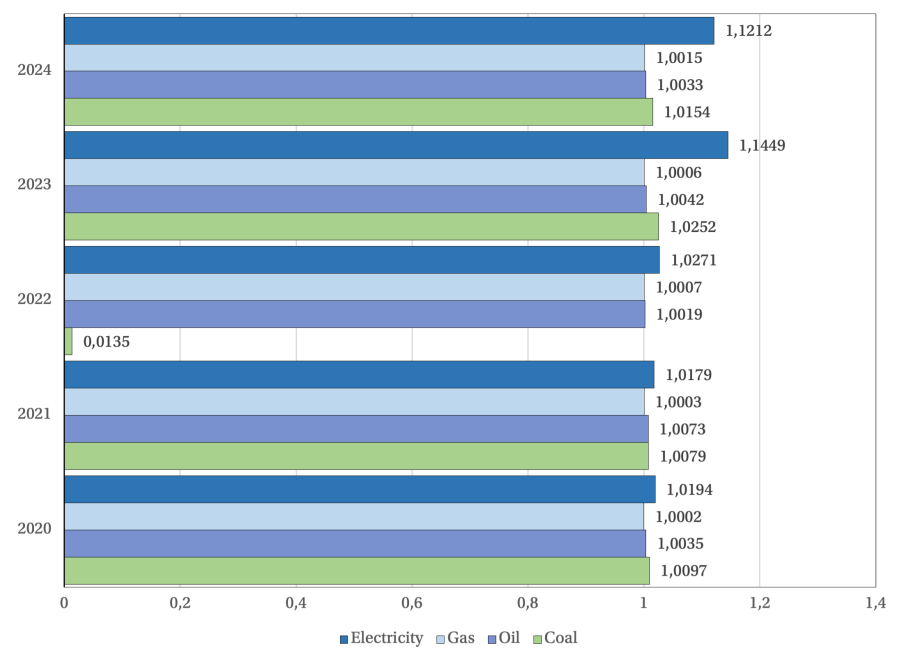


Figure 2. Diagonal elements of the Leontief inverse matrix for 2020–2024

The petroleum industry (industry 2, that is, element 2.2) has the lowest multiplier effect, always between 1,001863 and 1,007335. This indicates that its production links are weak, with relatively weak multiplier effects and limited indirect production linkages within the energy system. The multiplier effect of the natural gas sector (sector 3, that is, element 3.3) is also low (about 1,000179-1,001527), indicating that its role in the energy system is relatively small. However, it is expected to grow slightly by 2024. Overall, the results show a structural asymmetry in Kazakhstan's energy system: the electricity sector is the central node of the energy production network, coal remains a stable, basic resource, and the multiplier effect of oil and natural gas is relatively weak. Therefore, the Leontief input-output analysis demonstrates how the direct and indirect production linkages among the energy sectors changed during 2020-2024 and provides a quantitative assessment of the energy system's structural transformation.

Based on the Leontief inverse matrices, backward linkage (BL) and forward

linkage (FL) indicators were obtained for each sector and year. Figure 3 presents the BL indicators, while Figure 4 presents the corresponding FL indicators for 2020-2024.

Figures 3 and 4 present BL and FL indicators, respectively, for Kazakhstan's energy sectors during 2020-2024.

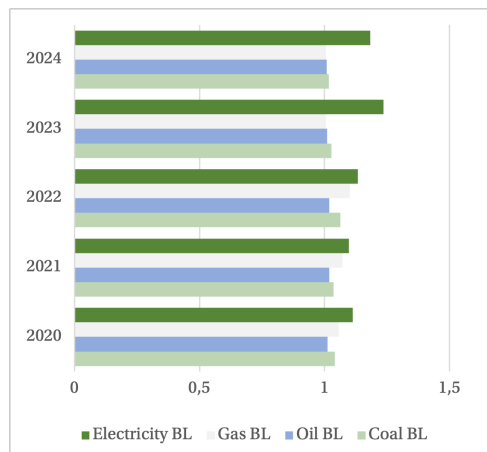


Figure 3. BL in the energy system for 2020-2024

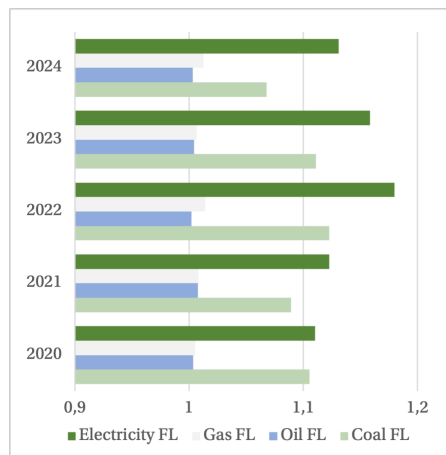


Figure 4. FL in the energy system for 2020-2024

BL and FL indicators from 2020 to 2024 reveal a gradual structural evolution in Kazakhstan's energy system. The BL indicator measures the degree of resource dependence in production sectors, highlighting how the system's cost structure evolves. In contrast, the FL indicator reflects a sector's capacity to distribute its products across the economic system, capturing their multiplier effects and overall influence. Examining these two indicators together provides a comprehensive understanding of the structural transformation of the energy sector, both in terms of production relationships and systemic interdependence.

The coal industry BL index showed only moderate fluctuations, peaking in 2022 and then gradually declining in 2024. The FL index also remained relatively stable, indicating that coal played a stable but not dominant role in providing energy to other energy sectors during the study period. The oil sector exhibits the most stable BL values, remaining virtually unchanged over time, suggesting a stable production structure and low resource dependence. In contrast, FL values were very high in 2020, indicating a relatively limited driving effect on the overall energy system, and they gradually declined in subsequent years, reaching their lowest point around 2023. This trend indicates a waning systemic influence of the oil sector and a broader diversification within the energy mix.

During the study period, the BL and FL values for the oil industry were the most stable. Both indicators were close to 1, indicating a relatively weak multiplier effect and limited changes in inter-industry production relations.

Compared with other industries, the BL value in the natural gas industry fluctu-

ated significantly, showing continuous growth until 2022, followed by a decline in 2023-2024. In contrast, the FL value remained relatively stable, indicating that its role as a supplier to the energy system has changed only marginally. Among all sectors, the energy sector consistently had the highest BL value, peaking significantly in 2023. Its FL value remained relatively high during the study period, confirming its central role in maintaining intersectoral production linkages in Kazakhstan's energy system.

Overall, the BL and FL indicators suggest that the intersectoral structure of Kazakhstan's energy system remained relatively stable during 2020-2024, although moderate changes in sectoral linkages were observed. The electricity sector consistently exhibited the strongest intersectoral influence, while the oil sector remained the most stable. Coal and natural gas experienced moderate variations, reflecting gradual adjustments in production relationships rather than fundamental structural transformation.

5 | CONCLUSION

This study examined how different parts of Kazakhstan's energy sector interacted from 2020 to 2024. This study used comparative input-output analysis based on annual Leontief input-output tables to examine the evolution of inter-industry production linkages in Kazakhstan's energy sector from 2020 to 2024. The analysis focuses on coal, oil, natural gas, and electricity production to assess changes in technological coefficients, inter-industry linkages, and production structure over time.

We found that the energy system slowly changed its structure over these years. How technology was used showed that some parts of the energy sector became less dependent on one another, while others became more internally connected. For example, the electricity sector relied more on its own production, meaning it used more resources from within the energy system and became more important overall. Coal and natural gas exhibited changes in their intersectoral production linkages, with several technical coefficients increasing through 2022 and then declining.

By looking at the connections between energy sectors, we could see the ripple effects. The electricity sector had the biggest impact on the whole system. Leontief's inverse analysis showed that the electricity sector consistently has the highest multiplier effect among the industries analyzed. Its multiplier effect increased significantly in 2023 and remained relatively high in 2024, confirming the central role of electricity generation in the energy system. The electricity sector functions as the central production node within Kazakhstan's energy system, generating the strongest direct and indirect intersectoral effects.

The coal industry multiplier remained relatively stable during the study period, indicating that it continues to play a supporting role in the production system. The oil industry showed the most stable technical and multiplier characteristics, with its BL and FL values approaching 1, indicating relatively weak indirect production linkages. The natural gas industry showed moderate fluctuations, especially in its BL value, indicating a gradual change in its production relations with other energy

sectors.

We also looked at how much each sector relied on others (Backward linkage) and how much it influenced others (Forward linkage). These helped us better understand their roles. The Backward linkage results indicate moderate differences in sectoral dependence on intersectoral inputs. The Forward linkage results confirmed that the electricity sector became the primary driver of the entire system. The BL and FL indicators further confirm the role of each sector in the production system. Among the energy sectors analyzed, electricity consistently exhibited the highest BL value, reflecting its high dependence on intersectoral resources and its central position in the production network. The relatively stable FL values for each sector indicate that the overall structure of intersectoral supply relations has undergone only gradual changes during the study period. In conclusion, these indicators suggest that Kazakhstan's energy system has undergone moderate structural changes rather than a radical transformation.

Thus, the comparative input-output analysis proved an effective approach for assessing changes in intersectoral linkages, the structural transformation of the production system, and the evolving interdependence among Kazakhstan's energy sectors. These findings are important for creating energy policies, improving how production is organized, and making smart choices to keep the energy system strong for the long run.

From a social perspective, the impact of structural changes in Kazakhstan's energy sector extends far beyond industrial production. Strengthening intersectoral linkages may contribute to employment stability, energy supply security, and regional economic development by improving the efficiency of energy production and resource allocation. A more balanced energy mix can also help lay a strong foundation for implementing long-term public policies to enhance national energy security and achieve sustainable economic growth and social well-being. The results of this study can help policymakers develop evidence-based energy strategies that combine economic efficiency with broader social development goals.

What we found also shows that the energy sector needs modern technology, more efficient resource use, and stronger links among its different parts. To make the system more stable in the future, it will be key to strengthen electricity's role as basic infrastructure, use more domestic resources, and improve how different sectors work together with technology.

However, our study had some limits. The analysis was based on a reduced four-sector input-output framework representing Kazakhstan's main energy industries, rather than the complete national input-output table. Therefore, the estimated multipliers characterize structural relationships within the energy subsystem rather than the entire national economy. Also, we mainly focused on economic connections and did not really consider environmental pollution or carbon emissions. So, future research could build on this by including environmental factors, such as carbon emissions and waste, and by adding the renewable energy sector. Furthermore, this analysis was conducted annually using comparative input-output tables and therefore does not account for capital accumulation,

investment dynamics, or time lags inherent in dynamic input-output models.

AUTHOR CONTRIBUTIONS

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