Research on Factors Affecting the Evaluation of Coal Utilization Efficiency

Lu Lv[1,*], Rong Wu[1], Ye Lv[2]
[1]*Wanjiang University of Technology, Maanshan, Anhui, China*
[2]*Anhui Institute of Information Technology, Wuhu, Anhui, China*
**Corresponding Author*

Abstract: China's energy resource endowment structure of "rich coal, less oil and poor gas" determines that coal is China's main energy resource. In recent years, the extensive development model makes the sustainable development of coal cities face difficulties and severe challenges. Therefore, improving coal utilization is the inevitable choice for resource-based cities to realize transformation and green development. In order to improve the coal utilization efficiency, based on the existing coal utilization efficiency evaluation index system, this paper obtains the influencing factors of coal utilization efficiency evaluation, analyzes the interaction between the influencing factors by DEMATEL method, and identifies the key influencing factors. It is found that coal utilization energy consumption, urbanization level and comprehensive utilization rate of associated minerals are three key influencing factors, and the countermeasures to improve coal utilization efficiency are put forward according to the analysis results.

Keywords: Coal Utilization Efficiency; DEMATEL; Influencing Factors

1. Introduction

1.1 Research Background and Significance

China's energy endowment — defined by rich coal reserves alongside limited oil and natural gas resources — means coal has long served as the core driving force behind the country's industrial development. It accounts for the largest share of China's energy consumption structure, and remains the nation's dominant primary energy source. [1] Energy development was positioned as a key pillar of ecological civilization construction, with a clear focus on advancing green development. What has emerged is a clear roadmap for transforming the coal industry in the new era. Most coal-resource-based cities grew up around coal mining and thrived on it, and their sustainable development is vital for national socioeconomic progress and energy security. In recent years, however, the extensive, low-efficiency development model has severely strained the sustainable growth of these coal-dependent cities and posed formidable challenges. Against this backdrop, improving coal-use efficiency is both an urgent imperative and a strategic route for resource-dependent cities to achieve industrial transformation and green development. Understanding the factors that influence how coal utilization efficiency is measured is a prerequisite for guiding the green transition of coal-resource-based cities.

Drawing on well-tested research frameworks, this study builds a comprehensive set of indicators to assess coal utilization efficiency and then uses it to tease out the relevant influencing factors. We further conduct a systematic analysis of the interrelationships and weight distributions among these factors, so as to uncover the core driving forces behind efficiency outcomes. Work along these lines has considerable practical value for improving overall coal utilization efficiency, and efficiency gains themselves act as a central lever for moving the coal industry away from its traditional resource-intensive model and toward a high-technology development trajectory. [2] Better coal use efficiency not only helps optimize and upgrade local industrial structures, but also creates more favorable conditions for the long-term, sustainable development of the coal industry as a whole.

1.2 Literature Review

International studies on coal development and utilization have mostly been conducted around the ecological and environmental effects involved. Baoliu Zhang et al. [3] used the life cycle assessment (LCA) method to look into the environmental consequences of coal extraction, processing, use, and transportation, and on that basis put forward solutions and countermeasures for coordinating energy development with environmental protection. Li Li et al. [4], taking the Shanxi coal mining area as a case, built a multi-objective optimization model, which was then used to design green development policies and evaluate how well they were implemented, thus helping to push forward economic, environmental, and resource objectives in a more coordinated manner. A significant step forward came from Wang Ning et al. [5], who built a LEEC (Life-cycle Energy Efficiency of Coal) model covering the entire coal life cycle. This provides a foundation for deeper inquiry into energy efficiency across industrial chains and whole systems. Zhai Xiaowei et al. [6] examined the ties between socioeconomic development and the emission of industrial “three wastes” (wastewater, waste gas, and solid waste) in Yulin City, Shaanxi Province, adding to the research on environmental sustainability in coal-resource cities.

Against the backdrop of the United Nations 2030 Agenda for Sustainable Development — a framework centered on building sustainable cities and human settlements — international academic research has examined coal development and utilization from a full lifecycle perspective, and made solid progress in advancing the coordinated development of energy and the environment. That said, a clear research gap still exists in the identification of critical influencing factors for coal utilization efficiency evaluation. For this reason, pinpointing the key drivers that affect coal utilization efficiency assessments has become a particularly pressing priority to support the sustainable development of resource-dependent cities. [7]

1.3 Main Research Content

The analytical approach adopted in this study is built around four main phases. We start by pinning down exactly what “coal utilization efficiency” means in this study. Once that conceptual boundary is clear, we lay out the basics of the DEMATEL method [8] and the MATLAB scripts used for the quantitative work that follows. Next, we draw on the existing evaluation framework for coal development and utilization efficiency to distill a representative set of influencing factors. DEMATEL is then used to tease out how these factors interact, with all the related matrix calculations run in MATLAB to produce a comprehensive correlation matrix. From that matrix, we work out the weight of each factor and zero in on the core driving determinants. Finally, the empirical results inform a set of targeted, practical policy suggestions for lifting coal utilization efficiency.

2. Related Concepts and Theoretical Foundations

2.1 Definition of Coal Utilization Efficiency

Academics still haven't agreed on a single, rigorous definition of coal utilization efficiency [9]. In this study, coal utilization efficiency is defined as the extent to which coal use supports regional development needs, reflected in its contributions to local residents’ quality of life, material well-being, cultural advancement and ecological conditions. Evaluating coal utilization efficiency is far more than a technical task — it is a complex management undertaking that touches on a host of interconnected factors, including resource endowment, management systems, technical capacity, equipment conditions, environmental impacts, safety performance and product outputs. For the sake of systematic analysis, these factors can be classified into four core evaluation dimensions: economic efficiency indicators, social efficiency indicators, resource efficiency indicators, and environmental efficiency indicators.

2.2 The DEMATEL Method

The Decision-Making Trial and Evaluation Laboratory, commonly shortened to DEMATEL and sometimes called the Decision Laboratory Analysis method, was first introduced in 1971 by researchers at the Battelle Memorial Institute in Geneva, Switzerland. Rooted in matrix theory and graph theory, the method provides a systematic way to examine the internal elements of a system and is especially useful for tackling complex social issues. It draws on expert knowledge and empirical judgment to map out how different factors within a system interact with one another and to determine where each factor sits in the overall hierarchy. By working through this kind of analysis, one can pinpoint the key driving factors behind a given research problem and thus create a starting point for shaping targeted improvements. Over the years, DEMATEL has been widely applied across a number of fields, including sociology, economics, management science and related areas.

The typical workflow begins by clearly defining the research problem and identifying the influencing factors at play. Second, Construction of the Direct Influence Matrix. Based on expert assessments, the pairwise interrelationships among factors are quantified to construct the direct influence matrix. Third, Normalization of the Direct Influence Matrix. The direct influence matrix is normalized to derive the normalized direct-relation matrix through matrix normalization procedures. Fourth, Computation of the Total Influence Matrix. The total influence matrix T is calculated based on the normalized matrix. Fifth, Calculation of Influence Parameters. Based on the total influence matrix T, four key parameters are computed for each factor: Prominence 、Relation、Centrality、Causality.

2.3 Matrix Computation Using MATLAB

The concept of a matrix has its roots in the square arrays of coefficients used in systems of linear equations, and it was the 19th-century British mathematician Arthur Cayley who first gave it a formal shape. In programming, an array is simply an ordered collection of variables of the same data type, structured to make computation faster and more straightforward. MATLAB blurs the line between the two, because matrices are actually stored and manipulated as arrays under the hood [10]. A one-dimensional array is essentially a vector; a two-dimensional array, an ordinary matrix. In that sense, matrices can be seen as a special case within the broader family of arrays. Everyday matrix operations include constructing matrices, adjusting dimensions, resizing, indexing elements, pulling out attribute information, and reshaping structures — and MATLAB comes with built-in functions and library routines for all of these tasks. In this study, we use MATLAB to convert the direct influence matrix into a normalized influence matrix, and then from that normalized form we compute the total influence matrix, which lays the groundwork for the analysis that follows.

3. Evaluation Index System for Coal Utilization Efficiency and Indicator Analysis

3.1 Evaluation Index System for Coal Utilization Efficiency

Song Xiaoyan and her colleagues wanted an evaluation framework for coal development and utilization efficiency that would work across different contexts under a green development lens. So they dug into the existing literature and also reached out to experts — sending questionnaires to people in mining and mineral processing to collect their views and feedback.

They built the index system in three stages. They started with a rough set of indicators pulled from the literature, then sharpened it by sifting qualitative and quantitative indicators separately. The goal was to keep it deep enough to capture the issue, but still practical and measurable. The final stage produced the definitive evaluation index system for coal development and utilization efficiency in resource-based cities under the green development paradigm; the full structure is laid out in Table 1.

The analysis laid out above, together with the index framework shown in Table 1, makes it clear that the evaluation index system for coal development and utilization efficiency has by now reached a fairly mature and well-rounded state. Building on this validated system, we select and settle on the set of influencing factors that feed into the assessment of coal utilization efficiency. The index system we construct for this research is presented in full in Table 2.

As shown in Table 2, this study approaches the selection from four dimensions—namely, economic efficiency, social efficiency, resource efficiency, and environmental efficiency—and identifies eight influencing factors for coal utilization efficiency evaluation, thereby constructing a comprehensive evaluation index system for coal utilization efficiency. From the perspective of economic efficiency, two indicators are selected: energy consumption of coal utilization and urbanization level. From the perspective of social efficiency, two indicators are selected: employment growth rate and poverty alleviation effect. From the perspective of resource efficiency, two indicators are selected: comprehensive utilization rate of associated and companion minerals and mineral processing recovery rate. From the perspective of environmental efficiency, two indicators are selected: comprehensive utilization level of "three wastes" (wastewater, waste gas, and solid waste) and land reclamation rate.

Table 1. Finalized Evaluation Index System

Primary Indicator	Secondary Indicator	Tertiary Indicator	Evaluation Criterion	Indicator Type
Economic Efficiency (A)	Economic Structure (A1)	Mechanization level of mining (A11)	Percentage	Quantitative
		Energy consumption of coal development and utilization (A12)	Percentage	Quantitative
	Economic Growth (A2)	Urbanization level (A21)	Percentage	Quantitative
		R&D and technological transformation investment intensity (A22)	Percentage	Quantitative
Social Efficiency (B)	Quality of Life (B1)	Employment growth rate (B11)	Percentage	Quantitative
		Employee education, health, and safety protection (B12)	Excellent, Good, Average, Poor, Very Poor	Qualitative
	Living Conditions (B2)	Poverty alleviation effect (B21)	Percentage	Quantitative
		Infrastructure construction (B22)	Excellent, Good, Average, Poor, Very Poor	Qualitative
Resource Efficiency (C)	Resource Utilization Rate (C1)	Mining recovery rate (C11)	Percentage	Quantitative
		Mineral processing recovery rate (C12)	Percentage	Quantitative
		Comprehensive utilization rate of associated and companion minerals (C13)	Percentage	Quantitative
	Energy and Resource Consumption (C2)	Comprehensive energy consumption per unit of output value (C21)	Monetary value	Quantitative
		Energy consumption of coal development and utilization (C22)	Monetary value	Quantitative
Environmental Efficiency (D)	Environmental Protection (D1)	Degree of terrain and landform preservation (D11)	High, Relatively High, Average, Relatively Low, Low	Qualitative
		Compliance level of pollutant emissions (D12)	High, Relatively High, Average, Relatively Low, Low	Qualitative
	Environmental Remediation (D2)	Environmental protection investment scale (D21)	Monetary amount	Quantitative
		Comprehensive utilization level of "three wastes" (wastewater, waste gas, and solid waste) (D22)	Percentage	Quantitative
		Land reclamation rate (D23)	Percentage	Quantitative

Table 2. Evaluation Index System for Coal Utilization Efficiency

	Specific indicators
Economic Efficiency	Energy consumption of coal utilization(F1)
	Urbanization level(F2)
Social Efficiency	Employment growth rate(F3)
	Poverty alleviation effect(F4)
Resource Efficiency	Comprehensive utilization rate of associated and companion minerals(F5)
	Mineral processing recovery rate(F6)
Environmental Efficiency	Comprehensive utilization level of "three wastes"(F7)
	Land reclamation rate(F8)

3.2 Indicator Analysis

This study employed expert questionnaires as the primary data collection instrument. The survey panel included specialists, practitioners, and scholars with expertise in coal development and utilization. Following the specified protocol, 30 invited experts rated each factor pair on a scale from 0 (no influence) to 5 (extremely high influence). For every pairwise relationship, the modal score was extracted from the aggregated responses to construct the direct influence matrix. The resultant matrix, which underlies the evaluation of coal utilization efficiency, is shown in Table 3.

Table 3. Direct Influence Matrix of Influencing Factors

	F1	F2	F3	F4	F5	F6	F7	F8
F1	0	3	4	1	5	2	3	4
F2	4	0	4	4	3	5	3	3
F3	2	1	0	2	3	3	2	4
F4	1	2	3	0	1	2	1	1
F5	4	3	4	1	0	3	4	2
F6	3	2	1	1	2	0	3	4
F7	4	4	3	1	2	2	0	2
F8	3	2	3	3	2	4	1	0

Upon the establishment of the direct influence matrix, a normalization procedure was carried out in MATLAB. The maximum row sum of M served as the scaling denominator, by which every element of M was divided to produce the normalized direct-relation matrix N. Thereafter, the total influence matrix T was generated according to the canonical formula T = N (I − N)-1, which equivalently captures the cumulative effects of all direct and higher-order indirect influences. The final matrix T is exhibited in Table 4.

Table 4. Total Influence Matrix of Influencing Factors

	F1	F2	F3	F4	F5	F6	F7	F8
F1	0.326	0.364	0.469	0.242	0.454	0.395	0.373	0.452
F2	0.490	0.289	0.499	0.360	0.420	0.520	0.400	0.458
F3	0.314	0.234	0.246	0.223	0.316	0.345	0.270	0.374
F4	0.197	0.199	0.268	0.104	0.181	0.234	0.171	0.200
F5	0.447	0.355	0.452	0.231	0.279	0.409	0.395	0.380
F6	0.346	0.269	0.285	0.189	0.285	0.239	0.301	0.371
F7	0.412	0.358	0.387	0.214	0.321	0.346	0.229	0.345
F8	0.353	0.274	0.360	0.264	0.296	0.388	0.249	0.253

Finally, the interrelationships among the influencing factors were quantified according to the DEMATEL model calculation formulas, and the resultant comprehensive interrelationship matrix is presented in Table 5.

Drawing from the results presented in Table 5, causal factors should be prioritized in efforts to enhance coal utilization efficiency. This is attributable to their pronounced driving effects on other variables and their relative rigidity in response to intervention, whereas effect factors are comparatively more tractable in terms of adjustment. The causal set comprises urbanization level, the comprehensive utilization rate of associated and companion minerals, the level of "three wastes" utilization, and energy consumption associated with coal utilization. Among all factors, energy consumption of coal utilization (weight = 0.144), urbanization level (weight = 0.140), and the comprehensive utilization rate of associated and companion minerals (weight = 0.133) rank as the top three in terms of weight, underscoring their paramount importance in determining coal utilization efficiency.

Table 5. Summary Table of Impact Relationships

	Prominence	Relation	Centrality	Causality	Weight
F1	3.075	2.885	5.960	0.190	0.144
F2	3.436	2.342	5.778	1.094	0.140
F3	2.322	2.966	5.288	-0.644	0.128
F4	1.554	1.827	3.381	-0.273	0.082
F5	2.948	2.552	5.500	0.396	0.133
F6	2.285	2.876	5.161	-0.591	0.125
F7	2.612	2.388	5.000	0.224	0.121
F8	2.437	2.833	5.270	-0.396	0.127

Building on the above analytical results, this paper puts forward the following targeted policy implications: First, coal consumption intensity serves as the core determinant of utilization efficiency. Coal-resource-based cities and relevant enterprises need to address the prominent problems of extensive energy waste and structural mismatch in coal utilization. Second, urbanization level exerts a marked influence on coal utilization efficiency within the framework of national macro-regulation. Cities should advance the upgrading of mechanized, automated and intelligent production systems, while deepening industry-university-research collaboration to speed up the commercial transformation of research findings. Third, aligned with the green development philosophy, priority should be given to the comprehensive utilization of associated minerals, paragenetic minerals and the "three wastes". Such efforts can minimize ecological damage caused by resource extraction, and support the transition toward a sustainable development model.

4. Conclusion

This investigation employs the DEMATEL technique to scrutinize the determinants of coal utilization efficiency, yielding a weighted ranking of the relevant indicators. The resulting findings carry significance on two fronts. First, these results lay a solid quantitative foundation for future research on coal utilization efficiency. Second, the derived weights make it possible to identify the indicators that most strongly shape the evaluation, which in turn helps design more targeted and effective improvement strategies. The findings, therefore, provide both a theoretical reference and practical guidance for policymaking and operational improvements.

That said, a few methodological limitations are worth noting. The indicator system was built with a preference for variables that offer good data availability and completeness, so the current framework inevitably depends on what data can be obtained and is not claimed to be final or exhaustive. On the positive side, the DEMATEL method is flexible enough to allow the indicator set to be adjusted or expanded as research goals shift or conditions change. Future studies will carry out more extensive empirical testing to advance this line of research, while keeping a close eye on pragmatic ways to raise coal utilization efficiency.

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