

EFFICIENCY-BASED PERFORMANCE ANALYSIS OF INDIAN COAL MINING FIRMS**Akankika Tripathy^{1*} and Dr. Debendra Kumar Mahalik²**¹Department of Business Administration, Sambalpur University, Odisha, 768019²Professor, Department of Business Administration, Sambalpur University, Odisha, 768019**ABSTRACT**

The coal mining industry plays a significant role in Indian economy by catering the energy demand of various industry. However, the sector is highly capital intensive and its investments are often associated with long gestation period, irreversibility and multiple uncertainties. The critical nature of the industry makes it essential to strategically evaluate the efficiency of the investment decisions taken by this industry and also to identify the best strategy that will contribute towards growth and high return. So, the present study focuses on examining the technical efficiency of seven subsidiaries of Coal India Limited (CIL) over a ten-year period using Data Envelopment Analysis (DEA) and Super-Efficiency DEA model. The study adopts a quantitative and longitudinal approach to study the secondary panel data collected from the annual reports of CIL and its subsidiaries. Thereafter an output-oriented Constant Returns to Scale (CRS) DEA framework was applied to evaluate the relative efficiency of each subsidiary taking them as independent Decision-Making Unit (DMU). The study found a significant variation in efficiency performance among the subsidiaries over the period. The Mahanadi Coalfields Limited (MCL) consistently achieved full efficiency scores among all firms indicating it to be the most efficient and stable subsidiary.

INTRODUCTION

India's increasing energy demand and its overall economic aspirations have continued to be largely dependent upon coal mining. As such, this dependence continues to influence the Government of India's decisions regarding industrial policy (the rules governing how business can operate in the country) and public investment priorities throughout the country. Most of the industry is controlled by state-owned companies, such as Coal India Limited and its seven subsidiaries. Given the amount of capital that is required for mining operations, along with the high risk involved with long-term development projects, determining which subsidiaries are using their own resources effectively is not just an academic exercise, but has significant implications for investment planning, operational strategies, and the country's overall energy security.

This study compares the technical efficiencies of CIL's seven subsidiaries over a decade based on several factors affecting the firms' ability to invest efficiently (e.g., capital labour utilisation, operational cost, infrastructure strength and capacity). Profitability and ROI are also measured in order to gauge how these inputs have been converted into economic outcomes. The findings indicated a significant variation in the performance of the subsidiaries of CIL over the period as the capital-intensive industry is associated with multiple uncertainties. These subsidiaries show a very good performance at different time while also has shown very low performance at other times due to geological constraints, policy change, labour issues and variation customer demand.

MCL has achieved an unusual operational efficiency over the period with a large-scale production, something in such a complex mining environment marked by escalating extraction costs and regulatory pressures. The efficiency is a benchmark for the other companies in the sector for capital investment decisions making process aligning managerial coordination, and technical capability over time. However, efficiency figures alone cannot fully capture environmental concerns, social displacement, or long-term sustainability challenges associated with coal extraction. Even so the evaluation of the reasons that make MCL comparatively resilient may will guide the investment decisions of other subsidiaries attempting to improve performance under similar constraints.

LITERATURE REVIEW

The analysis of capital investment efficiency in the coal mining sector involves a multifaceted approach, incorporating various methodologies and factors that influence investment outcomes.

Principal Component Analysis (PCA) has been employed to evaluate the capital construction investment efficiency in coal mines, as demonstrated in a study of 13 coal mines in Shanxi province, which categorized them into three efficiency levels based on comprehensive scores ranging from 3.813 to -1.141 (Zhao et al., 2014). Data Envelopment Analysis (DEA) is another prevalent method used to assess the operating efficiency of coal companies, focusing on technology, pure technology, and scale efficiency, which helps in identifying benchmarks for performance improvement (Chunguang, 2010) (Reddy, 2015). The economic efficiency of investments in coal deposits is also assessed through specific formulas that consider the internal income of enterprises, aligning with national income indicators to evaluate the financial basis for state functioning (Serov & Tikhonov, 2024).

The application of Data Envelopment Analysis (DEA) in evaluating the performance of coal mining firms, particularly within Coal India Limited (CIL), has predominantly focused on cross-sectional analyses, often neglecting the longitudinal and firm-specific efficiency assessments that could provide deeper insights into performance evolution over time. The existing literature, as reviewed by Baker, highlights the potential of internal benchmarking using DEA, which allows for the assessment of efficiency within a single organization over time, thus addressing the challenge of finding appropriate external comparators (Baker, 2023). Mahapatra et al. employed DEA and the Malmquist Productivity Index (MPI) to assess the efficiency of Indian opencast mines over a three-year period, revealing that only a few mines showed continuous improvement, while many experienced declining efficiencies, indicating the need for a more nuanced, longitudinal approach to efficiency assessment (Mahapatra et al., 2020). The use of super-efficiency DEA models, as discussed by Wu Jie, further underscores the importance of evaluating individual enterprise performance, identifying areas for improvement, and suggesting that efficient enterprises should focus on technological and managerial enhancements to maintain their competitive edge (Jie, 2011). Additionally, the integration of time series analysis with DEA, as proposed by Kaur, offers a promising method for addressing the limitations of single-period assessments by clustering data over multiple periods to establish more consistent benchmarks (Kaur, 2022).

The empirical study by Wang et al. also supports the use of hybrid models combining DEA with other analytical techniques to provide a comprehensive view of performance over time, which could be applied to CIL to better understand its subsidiaries' efficiency dynamics (Wang et al., 2015). Overall, while DEA has been extensively used in the coal industry, there remains a significant opportunity to apply longitudinal and firm-specific analyses to CIL, leveraging internal benchmarking and advanced DEA models to gain a more detailed understanding of performance trends and drivers.

RESEARCH METHODOLOGY

This section outlines the methodological framework adopted to evaluate the relative efficiency of selected coal mining subsidiaries under Coal India Limited (CIL) over a ten-year period. The aim is to identify consistent performers and assess the strategic positioning of Mahanadi Coalfields Limited (MCL) in relation to its peers. A non-parametric frontier analysis approach has been employed to measure technical efficiency, track performance trends, and identify best-practice benchmarks.

Research Design

The present research adopts a quantitative, longitudinal, and comparative design to examine the efficiency performance of major coal mining subsidiaries operating under Coal India Limited (CIL). Rather than limiting the analysis to a single year or isolated operational outcomes, the study traces efficiency patterns across a ten-year period, allowing changes in performance and productivity trends to become more visible over time. Operational data from seven subsidiaries, namely BCCL, ECL, CCL, NCL, SECL, WCL, and MCL, were compiled and analysed across multiple input and output dimensions. Such a framework enables both inter-firm and intra-firm comparisons, making it possible to evaluate not only how subsidiaries perform relative to one another but also how consistently they maintain efficiency over different periods.

A longitudinal approach appears especially relevant in the context of coal mining because operational efficiency in this sector is rarely static.

Production capacity, labour productivity, technological adaptation, reserve conditions, and capital deployment often fluctuate due to regulatory changes, geological uncertainties, and market conditions. Therefore, examining efficiency across a decade offers a more comprehensive understanding of performance dynamics than short-term assessments alone.

Data Collection

The study is based entirely on secondary data collected from the published annual reports of Coal India Limited and its subsidiaries. The dataset is panel in nature and covers a ten-year period. Information was compiled systematically to ensure consistency and comparability across all selected subsidiaries and years.

The selection of input and output variables was guided by two primary considerations. First, the variables needed to reflect operational and financial dimensions closely associated with production efficiency and capital utilization in the coal mining sector. Second, only those variables with reliable and consistently available data across all subsidiaries and years were included in the analysis. This was particularly important because mining datasets often suffer from reporting inconsistencies and missing observations, which can distort efficiency measurement if not addressed carefully.

Analytical Framework

To evaluate technical efficiency, the study employs Data Envelopment Analysis (DEA), a non-parametric linear programming technique widely used for measuring the relative efficiency of Decision-Making Units (DMUs) involving multiple inputs and outputs simultaneously. DEA is particularly suitable for mining-sector analysis because it does not require the specification of a predefined production function, which is often difficult to establish in industries characterized by varying geological and operational conditions.

The analysis applies a Constant Returns to Scale (CRS) DEA model to estimate overall technical efficiency among the selected subsidiaries. Under the CRS assumption, outputs are expected to change proportionally with changes in input levels. Although mining firms may not always operate under perfectly constant scale conditions in practice, the CRS model provides a useful benchmark for evaluating comparative operational efficiency across firms of different scales.

In addition to the standard DEA model, a Super-Efficiency DEA approach was employed to rank efficient units more precisely. Conventional DEA models frequently assign identical efficiency scores to multiple efficient firms, making differentiation difficult. The super-efficiency model addresses this limitation by evaluating efficient firms beyond the traditional efficiency frontier, thereby enabling clearer ranking among high-performing subsidiaries.

The study adopts an output-oriented DEA approach. This orientation focuses on determining the extent to which outputs can be proportionally increased while maintaining the existing level of inputs. Such an approach appears particularly relevant for the coal mining sector, where major inputs such as infrastructure, capital equipment, and workforce cannot easily be reduced in the short term due to the capital-intensive nature of operations. Consequently, improving output generation from existing resources becomes a more practical managerial objective.

Each subsidiary-year combination was treated as an independent Decision-Making Unit (DMU), allowing the study to track efficiency movements across time rather than producing only static firm-level results. This structure provides a more detailed understanding of how operational efficiency evolves under changing economic, technological, and regulatory conditions.

Data preparation, organization, and analysis were conducted using R software, which provided flexibility for handling panel datasets and implementing DEA models efficiently.

Procedure for Super-Efficiency DEA Computation

The computation of Super-Efficiency DEA scores followed a structured analytical process. Initially, operational data for the seven subsidiaries across ten years were organized into panel-data format. Each row represented a unique firm-year observation treated as a Decision-Making Unit (DMU), while the columns represented selected input and output variables.

This structure enabled consistent comparison across subsidiaries as well as across different time periods. After data organization, the selected input and output variables were incorporated into the DEA framework to estimate technical efficiency scores for each DMU. Subsequently, the Super-Efficiency DEA model was applied to rank efficient units beyond the conventional efficiency boundary.

The variables selected as inputs and outputs, discussed in the following section, were intended to capture broader dimensions of operational capability, capital utilization, production performance, and financial outcomes within the coal mining industry.

Table 4.1: Contributing variables to investment decision making

Index	Description	Kind
INPUTS	Capital	Input 1
	Operating Cost	Input 2
	Production Capacity	Input 3
	Infrastructure	Input 4
	Manpower	Input 5
	CSR	Input 6
	Environmental Exp	Input 7
	Safety	Input 8
OUTPUTS	Operating Profit	Output 1
	ROI	Output 2
	Demand	Output 3
	Productivity	Output 4

Next, a constant returns to scale (CRS), output-oriented model was applied to assess the ability of each firm to potentially expand its outputs while keeping inputs constant. This orientation aligns with the operational goals of coal firms that seek to maximize output under given resource constraints. Unlike traditional DEA models that assign a maximum efficiency score of 1.000 to all efficient units, the super-efficiency model was adopted to allow for further discrimination among efficient DMUs by enabling scores greater than one.

Once the model was defined, super-efficiency computation was initiated by excluding the evaluated DMU from its own reference set. This step ensured that each DMU was assessed solely against its peers, preventing self-comparison and enabling the identification of superior performers. For every DMU, following linear programming problem was formulated and solved.

Objective: Maximize θ

Subject to:

$$\sum_{j \neq o} \lambda_j x_{ij} \leq x_{io} \quad \text{for all inputs } i$$

$$\sum_{j \neq o} \lambda_j y_{rj} \geq \theta \cdot y_{ro} \quad \text{for all outputs } r$$

$$\lambda_j \geq 0 \quad \text{for all } j \neq o$$

λ_j : weight for peer DMU j

x_{ij} : input i of DMU j

y_{ij} : output i of DMU j

The objective function of the DEA model was designed to maximize the output expansion factor (θ), while satisfying a set of input and output constraints. More specifically, the model ensured that the weighted combination of peer inputs did not exceed the input levels of the Decision-Making Unit (DMU) under evaluation. At the same time, the weighted combination of peer outputs was required to equal or surpass the proportionally scaled outputs of the evaluated DMU. In simpler terms, the framework examined whether a subsidiary could potentially generate higher outputs using the same level of resources when compared with the best-performing peer units operating within the sample.

The optimization problems were solved using linear programming techniques implemented through R. For each DMU, the analysis generated a super-efficiency score representing its relative operational performance within the evaluated set of subsidiaries. A score equal to one indicated that the DMU was technically efficient and positioned on the efficiency frontier. Scores greater than one reflected super-efficient units that performed beyond the benchmark frontier established by peer firms, whereas scores below one represented relatively inefficient units with scope for operational improvement.

Once the efficiency scores were computed, the results were organized into a time-series framework to observe performance behaviour across the ten-year study period. This longitudinal arrangement proved useful because efficiency in mining operations is rarely stable from year to year. Factors such as production disruptions, changing reserve conditions, technological upgrades, labour productivity, or shifts in investment allocation can significantly influence operational outcomes over time. Tracking the scores longitudinally therefore allowed the study to capture both performance consistency and fluctuations across subsidiaries.

The super-efficiency scores were subsequently analysed from both year-wise and firm-wise perspectives to identify consistently high-performing subsidiaries within Coal India Limited. Through this comparative assessment, Mahanadi Coalfields Limited (MCL) emerged as the most efficient subsidiary in the sample, consistently achieving efficient or super-efficient scores throughout the observed period. Its sustained performance, particularly when compared with subsidiaries experiencing fluctuating efficiency levels, strengthened its selection as the focal organization for deeper analysis within the broader research framework.

To support interpretation and facilitate comparative understanding, the computed efficiency values and temporal performance trends were further visualized using line graphs. These graphical representations helped illustrate the movement of efficiency scores across years, making patterns of stability, improvement, or decline more observable and analytically meaningful.

RESULT & DISCUSSION

The primary objective of this analysis is to identify the most efficient and best-performing subsidiary among the selected firms: Bharat Coking Coal Limited (BCCL), Eastern Coalfields Limited (ECL), Central Coalfields Limited (CCL), Northern Coalfields Limited (NCL), South Eastern Coalfields Limited (SECL), Western Coalfields Limited (WCL), and Mahanadi Coalfields Limited (MCL).

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The use of a super-efficiency DEA model enables us to go beyond traditional efficiency scores and distinguish firms that consistently outperform others, even when they lie on the efficient frontier. The super efficiency of each firm evaluated over a year of 10 years has been computed and shown in table 1 below;

Table 4.2: output-oriented CRS DEA super-efficiency scores

Year	BCCL	ECL	CCL	NCL	SECL	WCL	MCL
2014	1.000	1.000	1.000	0.204	1.000	0.845	1.000
2015	0.991	1.000	1.000	0.945	1.000	0.869	1.000
2016	0.974	0.999	1.000	0.994	1.000	0.876	1.000
2017	0.991	0.990	0.970	0.999	1.000	0.795	1.000
2018	0.937	0.994	0.981	1.000	1.000	0.920	1.000
2019	0.977	1.000	0.961	0.999	0.981	0.911	1.000
2020	0.978	0.994	0.980	1.000	1.000	0.915	1.000
2021	0.720	0.949	1.000	1.000	1.000	0.913	1.000
2022	0.876	0.726	1.000	1.000	1.000	0.970	1.000
2023	0.911	0.720	1.000	1.000	0.981	0.979	1.000

This table provides technical efficiency scores under Constant Returns to Scale (CRS) and output orientation for seven coal sector DMUs across 10 years. Each score reflects how efficiently a DMU converts inputs into outputs, with 1.000 indicating full efficiency. The table indicates sharp decline of efficiency in major firms from 2019 onwards and we have considered it as the impact of COVID during that period as it has impacted major of the sectors in terms of profitability and outputs. The efficiency of each firm is evaluated separately as shown through line graph below where;

1. BCCL (Bharat Coking Coal Limited)

BCCL demonstrates relatively strong operational efficiency during the initial years of the study period. In 2014, the firm achieved a perfect efficiency score of 1.000, indicating that it was operating directly on the efficiency frontier in comparison with peer subsidiaries. Between 2015 and 2018, the company continued to maintain near-optimal efficiency levels, with only marginal fluctuations in performance. This pattern suggests that BCCL was initially capable of utilizing its available resources effectively while maintaining competitive output generation.

However, the trend becomes less stable in the later years. A noticeable decline occurs in 2021, when the efficiency score falls sharply to 0.720. While efficiency deterioration can emerge from multiple factors, the timing coincides with the broader disruptions associated with the COVID-19 period, which affected labour availability, production continuity, transportation systems, and operational coordination across industries. It is possible that increased operational inputs or reduced productivity during this phase weakened BCCL's relative efficiency position. Although the firm demonstrates some recovery afterward, reaching 0.911 in 2023, it does not fully regain its earlier benchmark status. Overall, BCCL's trajectory reflects an organization that began as a strong performer but experienced operational setbacks that limited its long-term consistency.

2. ECL (Eastern Coalfields Limited)

Eastern Coalfields Limited (ECL) also begins the study period with relatively high efficiency performance. The subsidiary achieved a perfect efficiency score in 2015 and maintained scores close to the efficiency frontier during the surrounding years. This indicates that, during the earlier phase of the decade, ECL was comparatively successful in balancing resource utilization with output generation. The situation changes considerably after 2020. From 2021 onward, efficiency levels decline sharply, eventually reaching 0.726 in 2022 and further dropping to 0.720 in 2023. Such persistent deterioration suggests deeper operational inefficiencies rather than temporary fluctuations alone. The decline may reflect increasing input costs, stagnation in production growth, ageing infrastructure, lower productivity levels, or stronger improvements among competing subsidiaries. Whatever the precise combination of factors may be, the pattern indicates that ECL gradually lost its comparative efficiency

advantage over time. The consistency of the downturn in the later years implies a need for strategic reassessment, particularly regarding resource allocation, technological modernization, and operational productivity enhancement.

3. CCL (Central Coalfields Limited)

Central Coalfields Limited (CCL) exhibits one of the most stable efficiency patterns among the evaluated subsidiaries. Across the ten-year period, the firm repeatedly achieves efficiency scores of 1.000 and records only very minor deviations below the frontier in certain years, such as 0.970 in 2017 and 0.961 in 2019. These fluctuations are relatively insignificant and do not indicate structural inefficiency within the organization. The overall trend reflects a high degree of operational consistency and effective resource management. Unlike firms that experience substantial efficiency volatility across years, CCL appears capable of maintaining stable production performance despite changing external conditions. Such consistency may result from balanced managerial practices, operational discipline, efficient workforce utilization, or sustained technological support systems. In relative terms, CCL stands out as one of the most dependable and consistently high-performing subsidiaries within Coal India Limited.

4. NCL (Northern Coalfields Limited)

Northern Coalfields Limited (NCL) presents one of the most interesting efficiency trajectories within the sample. The subsidiary begins the study period with a very low efficiency score of 0.204 in 2014, indicating substantial inefficiency relative to peer firms. Such a low score suggests that the organization was either utilizing excessive inputs, generating comparatively weak outputs, or facing significant operational constraints during the initial year. What follows, however, is a remarkable turnaround. From 2015 onward, NCL's efficiency performance improves dramatically, with scores consistently reaching or approaching the efficiency frontier in subsequent years. This sustained improvement suggests the implementation of meaningful operational reforms or strategic adjustments. The transformation may have involved improved production planning, technological upgrades, better infrastructure utilization, enhanced labour productivity, or stronger managerial coordination. While the exact causes would require deeper firm-level investigation, the pattern clearly reflects successful operational adaptation. NCL therefore represents an example of how targeted reforms and improved resource management can substantially improve long-term efficiency performance in capital-intensive industries.

5. SECL (South Eastern Coalfields Limited)

South Eastern Coalfields Limited (SECL) emerges as one of the benchmark performers throughout the analysis period. The subsidiary consistently achieves efficiency scores of 1.000 across nearly all years, with only a slight decline to 0.981 in 2023. Even this deviation remains extremely close to the efficiency frontier and does not meaningfully alter its strong performance position. SECL's sustained efficiency indicates a high level of operational productivity and effective input optimization over the decade. Its repeated appearance on the efficiency frontier suggests that other subsidiaries are frequently evaluated relative to SECL within the DEA framework. In many ways, the firm functions as a benchmark unit against which peer performance can be compared. Such consistency may reflect effective cost control mechanisms, strong managerial capability, technological integration, and stable operational planning. Maintaining such performance over a long period is not particularly easy in the mining industry, where fluctuations in production conditions and external disruptions are common. SECL's stability therefore reflects considerable institutional strength.

6. WCL (Western Coalfields Limited)

Western Coalfields Limited (WCL) consistently operates below the efficiency frontier throughout the observed period. Although its scores generally remain within the moderate range of approximately 0.79 to 0.97, the subsidiary never achieves full efficiency during the ten-year span. The highest recorded score of 0.979 in 2023 suggests some degree of recent improvement, but not enough to place the firm among the top-performing subsidiaries. The pattern indicates persistent operational inefficiencies relative to peer firms. Compared with subsidiaries that consistently maximize output from available inputs, WCL appears to struggle either with excessive resource utilization or insufficient production outcomes.

The underperformance is not severe enough to classify the firm as critically inefficient, yet the inability to reach the efficiency frontier across an extended period suggests underlying structural or managerial limitations. Improvements in operational productivity, technological adaptation, or resource allocation efficiency may help WCL strengthen its long-term performance position.

7. MCL (Mahanadi Coalfields Limited)

Mahanadi Coalfields Limited (MCL) stands out as the most consistently efficient subsidiary among all firms included in the study. From 2014 to 2023, MCL records perfect efficiency scores of 1.000 in every evaluated year, indicating continuous operation on the efficiency frontier throughout the entire study period. Such uninterrupted performance is particularly notable given the complexity and uncertainty typically associated with coal mining operations. MCL's sustained efficiency suggests highly effective resource utilization, stable production management, and strong organizational capability. The firm appears capable of consistently converting inputs into productive outputs more effectively than most peer subsidiaries. Its performance likely reflects a combination of efficient capital investment practices, operational planning, technological support, and managerial coordination. Within the DEA framework, MCL clearly functions as a model performer and a benchmark reference unit for comparative analysis. Unlike firms showing fluctuating or unstable efficiency patterns, MCL demonstrates sustained operational resilience over time, making it particularly valuable for understanding the broader relationship between capital investment decisions and organizational efficiency in the mining sector.

CONCLUSION

The present study sought to examine the efficiency dynamics of major coal mining subsidiaries operating under Coal India Limited (CIL) in order to support a deeper understanding of investment decision-making within the sector. Using an output-oriented DEA and Super-Efficiency DEA framework, the analysis evaluated the relative operational efficiency of seven subsidiaries over a ten-year period. Among all firms assessed, Mahanadi Coalfields Limited (MCL) consistently emerged as the strongest performer, maintaining full efficiency throughout the entire study period. Rather than relying on theoretical assumptions alone, the study grounds its investigation within the operational realities of a demonstrably high-performing mining organization. At the same time, the findings also highlight that efficiency is not static across firms. Several subsidiaries experienced fluctuations, periods of decline, or gradual recovery, indicating that organizational performance in mining is shaped by evolving economic, operational, and external conditions.

The analysis demonstrates the value of longitudinal DEA-based assessment in understanding performance dynamics within capital-intensive industries. By identifying benchmark firms and observing efficiency movement over time, the study contributes to a more nuanced understanding of how investment decisions translate into operational outcomes. The insights derived from MCL's sustained performance not only support the validity of the proposed investment decision-making framework but may also provide replicable strategic lessons for other mining enterprises operating under similar financial, technological, and resource constraints.

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