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Evaluating the Efficiency of Indian Cement Companies: An Integration of MCDM and Copeland Techniques

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Abstract: The study aims to appraise the efficiency of 28 cement-producing Indian companies for the year 2022–23, applying an innovative combination of various multi-criteria decision-making (MCDM) approaches. Initially, output-oriented data envelopment analysis (DEA) and super-radial DEA are employed to examine operational productivity and compute super-efficiency scores, considering three outputs and four inputs. The analysis reveals that 71% of the companies exhibit pure technical efficiency, while 54% demonstrate scale and overall technical efficiency. Among the operationally proficient companies, 60% are small ones, suggesting that industry powerhouses struggle to leverage economies of scale effectively. Furthermore, the super-efficiency scores, alongside financial productivity proxies – F-score, G-score, C-score, and M-score – served as parameters for applying multi-criteria analysis. Accordingly, the criterion weight and rank of the companies are determined using LOgarithmic Percentage Change-driven Objective Weighting (LOPCOW) and Axial Distance-based Aggregated Measurement (ADAM) methods, and Mangalam Cement appears as the frontrunner. However, different techniques of multi-criteria analysis may provide varied rankings due to deviations in computational methodology. Therefore, to strengthen the appraisal process, a two-phase sensitivity analysis was conducted, revealing a strong and significant association, as indicated by rank correlation coefficients and Friedman's test. Eventually, the paper consolidated the varied performance scores using the Copeland method, and Barak Valley Cements emerges as the outperformer. The final rank indicates that among the top 10 firms, 40% are small players, while within the bottom 10, 30% are large and mid-sized firms. Moreover, the decision of big players to acquire efficient small companies post 2022–23 aligns with our findings.

Keywords: Super-efficiency, Piotroski F-score, Mohanram G-score, Montier C-score, Beneish M-score, LOPCOW, ADAM

1. Introduction

India, a significant global friendly entity with a diversified and rapidly expanding economy, proudly holds the title of the world's fourth-largest nation in terms of gross domestic product (GDP). In this journey, the agricultural, manufacturing, and IT sectors are the key drivers. As a launch pad for advancement, these dynamic sectors demand robust and sustainable infrastructure. In this regard, India's cement industry, in particular, is pivotal not only for India but for the whole world, as it serves as a notable catalyst in the global market, making India the second-largest cement-producing nation after China. Therefore, this industry is an integral part of India's eight core industries and plays a crucial role in satisfying the nation's and global infrastructural requirements (Mudgal & Chellasamy, 2024), connecting India to the global economy.

India's abundant quantity and quality of limestone enable the installation of more than 8% of the global cement capacity, i.e., approximately 700 million tonnes per annum (MTPA) (CMA, 2025). India's cement market is expected to reach US$18.39 billion in 2025 (Research and Markets, 2025). This growth will be fuelled by the ongoing government's infrastructural investment, a booming housing sector, particularly in rural areas, and a selective resurgence in commercial and industrial construction. As of now, around 70% of India's total cement production is achieved by the top 20 firms, while private players hold about 98% of the total capacity (IBEF, 2025). Therefore, this highlights India's growing influence in the international cement landscape, reflecting its substantial manufacturing capabilities and a dynamic domestic market.

The Indian cement sector is also a crucial contributor to the broader economy (Maity *et al.,* 2019), providing direct employment to over one million people and generating substantial indirect employment opportunities across allied industries (Infomerics, 2024). Its deep inter-linkages with construction, real estate, transportation, and energy sectors create a powerful multiplier effect on Gross Domestic Product (GDP) and overall economic activity. Furthermore, due to numerous large-scale mergers and acquisitions in the cement sector during 2023–24 and 2024–25, along with the government's growing appetite for infrastructural and housing project expenditure, the production and demand for cement are projected to continue their upward trajectory. However, this sector also faces continuous challenges, mainly due to its capital & energy-intensive nature, as well as environmental concerns, as mentioned by Dasgupta & Das (2021) and Poudyal & Adhikari (2021). A recent study has identified the necessity of improving both efficiency and sustainable performance (Sangwan et al., 2019) to have a competitive edge. Hence, analysing firm level productivity will provide a clear picture of the cement industry (Shrivastava & RL, 2017; Morrow III *et al*., 2014), and may support sustainable goals.

Measuring a firm's productivity was previously financial ratio focused. It covers the financial aspect but overlooks other sides of performance (Seretidou *et al.,* 2025). This only gives a partial view of the firm's competitiveness. Studies have also suggested to include parameters like operational efficiency and governance (Kulkarni & Belavadi, 2025; Kazancoglu *et al.,* 2018; Moghimi & Anvari, 2014) to get a multi-dimensional view. The application of operational research and decision science in such situations can cover multiple areas. This may aid in a more comprehensive analysis (Hwang *et al.,* 2020; Exposito & Sanchis-Llopis, 2018) of the firm's performance. However, studies combining operational indicators and financial metrics are still very limited. This gap underscores the necessity for interdisciplinary study, which is crucial for both researchers and stakeholders. This study, therefore, positions itself at the intersection of operational research, financial analysis, and decision science to address interdisciplinary gaps and provide an extensive framework for evaluating and ranking Indian cement firms. Hence, considering the aforementioned gap and the gravity of the Indian cement sector, evaluating the efficiency and productivity of cement-producing companies and their relative performance appraisal becomes imperative.

Against this backdrop, the present paper primarily aims to assess the comprehensive efficiency of 28 listed cement companies, which account for 95% of the total market capitalisation and 91% of the total production capacity for the year 2022–23. In pursuit of this, the additional objectives are (i) to furnish the desired level of inputs and outputs to the inefficient companies, which may transform them into an operationally efficient firm, (ii) to evaluate and compute the operational efficiency score of the companies using DEA and super-radial DEA (super-efficiency), and (iii) to examine the association between the operational efficiency evaluation obtained by deploying various MCDM techniques.

The novelty of the proposed approach is attributed to its distinctive sequential methodology that integrates analytical techniques such as data envelopment analysis (DEA), multi-criteria decision-making (MCDM), and the Copeland method. This integrated and innovative approach may be beneficial to investors, stock analysts, and researchers for data-driven decision-making. Furthermore, it may offer valuable insights for corporate executives by providing performance benchmarks for gap analysis, identifying strengths and weaknesses, optimising resource allocations, fostering internal accountability, and guiding strategic decisions for mergers & acquisitions (M&A) and partnership alliances. Hence, this will improve the corporate reputation and foster stakeholders' trust, further ensuring a long-term competitive edge and sustained growth of the company.

2. Literature Review

The contribution of Charnes *et al.* (1978) and Banker *et al.* (1984) in the field of data envelopment analysis (DEA) is more than significant. They have inspired a large number of studies that lean on their foundational work. For example, the efficiency of 17 cement-producing firms of India was examined by Geetha & Ramasamy (2014) during 2001–02 to 2012–13. Using Compound Aggregate Growth Rate (CAGR) along with various financial ratios, they concluded that efficiency improved over that period. Similarly, Reddy & Saleem (2016) employed an Efficiency-Profitability Matrix approach to analyse the effect of cash profit on the efficiency of the top 10 cement-producing entities in India for the year 2013–14, using an input-oriented DEA. Their study found that two cement firms excelled in both efficiency and profitability, placing them in the star quadrant. Meanwhile, three companies were classified in the cash cow quadrant, as they were profitable but inefficient. Interestingly, half of the Indian cement firms analysed fell into the dog quadrant, where both inefficiency and low profitability were evident. Banerjee (2018) applied input-oriented VRS-DEA and computed a super-efficiency score to evaluate the efficiency of nine Indian cement companies across the pre-recession (2004–05 to 2006–07) and post-recession (2007–08 to 2009–10) periods. The paper found that in India, the recession had a limited effect on the efficiency of the cement sector. Abbasi & Kaviani (2016) applied uncertain DEA methods to evaluate and rank the operational performance of the Iranian cement industry. They concluded that ranking outcomes assisted management in strategising their operational decisions. Valizadeh Oghani *et al.* (2020) examined the management ability of the Iranian cement sector using the data envelopment model. They found that the proficiency of the firms was associated with acquired and inherent competencies of managerial personnel. Deb *et al.* (2025) measured the effect of CSR on the financial status of 87 Indian corporates using the free disposal hull and data envelopment analysis. The findings concluded that only 20 companies were technically efficient and had a positive association between ESG, efficiency, and ROA.

One of the initial conceptual developments of multi-criteria decision-making (MCDM) include Research work on "moral algebra" by Franklin (1772). Several studies thereafter have been done to organise decision-making problem. Studies have done also to build preference from alternatives. Kumar (2016) examined performance of 10 Indian cement enterprise between 2011 and 2015, applying MCDM with financial ratios. It was concluded that weak association exists between market capitalistion and TOPSIS rankings. JK Cement and Shree Cement were the worst and best performer, respectively. In a similar vein, Raikar (2018) used MCDM techniques, specifically AHP for identifying criterion weights and VIKOR for determining firm ranks, and measured the performance of the top 15 cement-producing firms in India for the period 2013–2017. His study found that Ambuja Cement, Ultratech Cement, and Orient Cement were the top performers. Kumar & Sharma (2024) carried out a study on the Indian banking sector. They concluded that Bandhan Bank was the leading performer after using CRITIC to identify the criteria weights and TOPSIS to derive the company rankings. Husain *et al.* (2024) employed eight ranking techniques – PIV, MARCOS, EDAS, MABAC, TOPSIS, WASPAS, GRA, and MOORA – to rank four renewable energy sources. They combined entropy and CRITIC to determine criteria weights and importance. According to their study, solar energy was the best alternative in the Indian context, followed by wind and biomass. Using financial ratios as criteria, Hajihassani (2015) used the Copeland method to rank the performance of 28 cement firms in Tehran from 2004 to 2009. The study revealed that the best-performing companies were Ardabil Lime Cement and Azar Shahr Cement. Kaya *et al.* (2024) attempted to outrank the 22 Turkish enterprises incorporated in the index of sustainability (excluding banks) by examining nine financial criteria for the period 2019 to 2021. Combining FUCOM to obtain the weights of the parameters and using nine ranking techniques — CoCoSo, TOPSIS, MAIRCA, GRA, OCRA, MABAC, TODIM, and MOOSRA in collaboration with the Copeland method, the paper concluded that TOASO was the leading performer.

Beyond the technical elements, recent scientific studies on DEA and MCDM have flourished to incorporate supply-chain performance, corporate governance, sustainability, socio-economic prospects, environmental and circular economy obstacles, and industrial regulatory frameworks.

Previous works have highlighted enormous attention on the cement industry's environmental ramifications owing to its energy intensity and carbon emissions, which are strongly determined by socio-economic prospects. For example, Fernando *et al.* (2024) evaluated the material selection process and developed a social assessment model for worker and social welfare. Akintayo *et al.* (2024) checked cement production methods by employing Life Cycle Assessment (LCA) in conjunction with MCDM. They affirmed that the environmental and administrative aspect enables the classification of greener manufacturing technologies. Using machine learning and MPI, Mirmozaffari *et al.* (2021) developed a model to measure eco-efficiency. A decision-support system to analyse energy efficiency was designed by Mokhtar & Nasooti (2020). Shi (2019) examined efficiency in the presence of desirable output and suggested a two-stage DEA.

Challenges in the nature of financial, technological, and policy are constant in the Indian cement industry, which hinders eco-friendly practices. Inadequate working environment is the main obstacle to green cement production, as observed by Marinelli & Janardhanan (2022), using the Best-Worst MCDM. Balsara *et al.* (2021) used fuzzy MCDM and found that market-related hurdles and institutional constraints are reasons that impede the application of climate migration strategies.

Keeping pace with sustainability and corporate governance, research studies moved in the same direction. Mehta *et al.* (2019) constructed a sustainability index for India using DEA and TOPSIS. Their study found a correlation between efficiency ranking and societal & environmental factors. Hoang *et al.* (2024) validated the association between governance indicators and sustainable development goals (SDGs) in decision-making, using DEA-MCDM. On top of that, Kumar *et al.* (2023) checked sustainability disclosures from Indian organisations using the GRI-G4 framework and MCDM strategies. Their analysis showed a substantial discrepancy in the quality and level of ESG reporting. Dasgupta & Das (2021) have drawn the same attention, highlighting that most of the Indian cement companies are gaining momentum steadily toward sustainability.

The potential of governance to link operational efficacy with ESG principles was underlined by Pishdar *et al.* (2021), who extended the governance and sustainability practice, employed fuzzy AHP, TOPSIS, and DEA, displaying how governance principles directly motivate decision-making techniques. Kazancoglu *et al.* (2018) equip similar results, utilising fuzzy DEMATEL to examine green supply chain management (GSCM) practices. They found that GSCM can reduce environmental impacts and enhance competitiveness at the same time. The correlation between governance and sustainable supply chain practices is further supported by Singh & Modgil (2020), who used SWARA-WASPAS to guide supplier selection in the Indian cement industry.

While a plethora of research works in the field of data envelopment analysis (DEA) and multi-criteria decision-making (MCDM) are available in isolation, the literature integrating both techniques in the context of the Indian cement sector is limited. This is particularly true when it comes to combining multiple parameters beyond operational efficiency to appraise companies using various MCDM techniques, and consolidating them using the Copeland method. In light of this, the current study stands out as it focuses exclusively on assessing and ranking Indian cement companies for the year 2022–23. What makes this study unique is its integrated and innovative approach, which promises to bring fresh insights and perspectives to the field.

3. Methodology

The current study focuses on the cement-producing entities listed on the Indian stock exchange. Due to data unavailability and inconsistency, the paper considers 28 companies/Decision-Making Units (DMUs), which account for 95% of the total market capitalisation and 91% of the total cement production capacity. The pivotal part of the study is to undertake performance appraisal and assign comprehensive ranks to the performance scores by engaging an integrated and innovative approach for the year 2022–23, as summarised in Figure 1. The reason for not considering the financial year 2023–24 for ranking is primarily due to the high-capacity mergers and acquisitions in the Indian cement sector during that period.

The paper initially assesses the operational efficiency of the 28 cement companies by computing Pure Technical Efficiency (PTE), Scale Efficiency (SE), and Overall Technical Efficiency (OTE) scores, engaging an output-oriented data envelopment analysis (DEA) (Farrell, 1957; Charnes *et al.*, 1978; Banker *et al.*, 1984), subsequently incorporating super-radial (CCR, CRS) DEA (Andersen & Petersen, 1993) to ameliorate the shortcomings inherent in traditional DEA. Moving forward, financial well-being metrics, such as Piotroski F-score (Piotroski, 2000) & Mohanram G-score (Mohanram, 2005), which reflect financial soundness and growth potential, alongside the Montier C-score (Montier, 2009) & Beneish M-score (Beneish, 1999), which signify potential financial shenanigans, are contemplated to present a holistic view of the company's financial efficiency. All five of these scores are used as parameters in the MCDM process. Consequently, the ranking outcome is derived employing a dynamic objective weight determination technique called LOPCOW (Ecer & Pamucar, 2022) and an enhanced ranking method called ADAM (Krstić *et al.*, 2023). Additionally, a two-phase sensitivity analysis is engaged to address the variation in results that may occur due to different computational methodologies of various MCDM techniques (Varmazyar *et al.*, 2016; Hobbs *et al.*, 1992). Going forward, the conventional and advanced rank correlation coefficients, as well as Friedman's test, provided a statistical validation for the sensitivity analysis. Eventually, a well-known rank aggregation method, the Copeland method (Copeland, 1951), consolidates the results obtained from different MCDM methods and sets a comprehensive rank. Hence, this integrated and innovative approach of appraising and ranking companies can be considered advanced and appropriate for providing a lucid depiction of the companies.

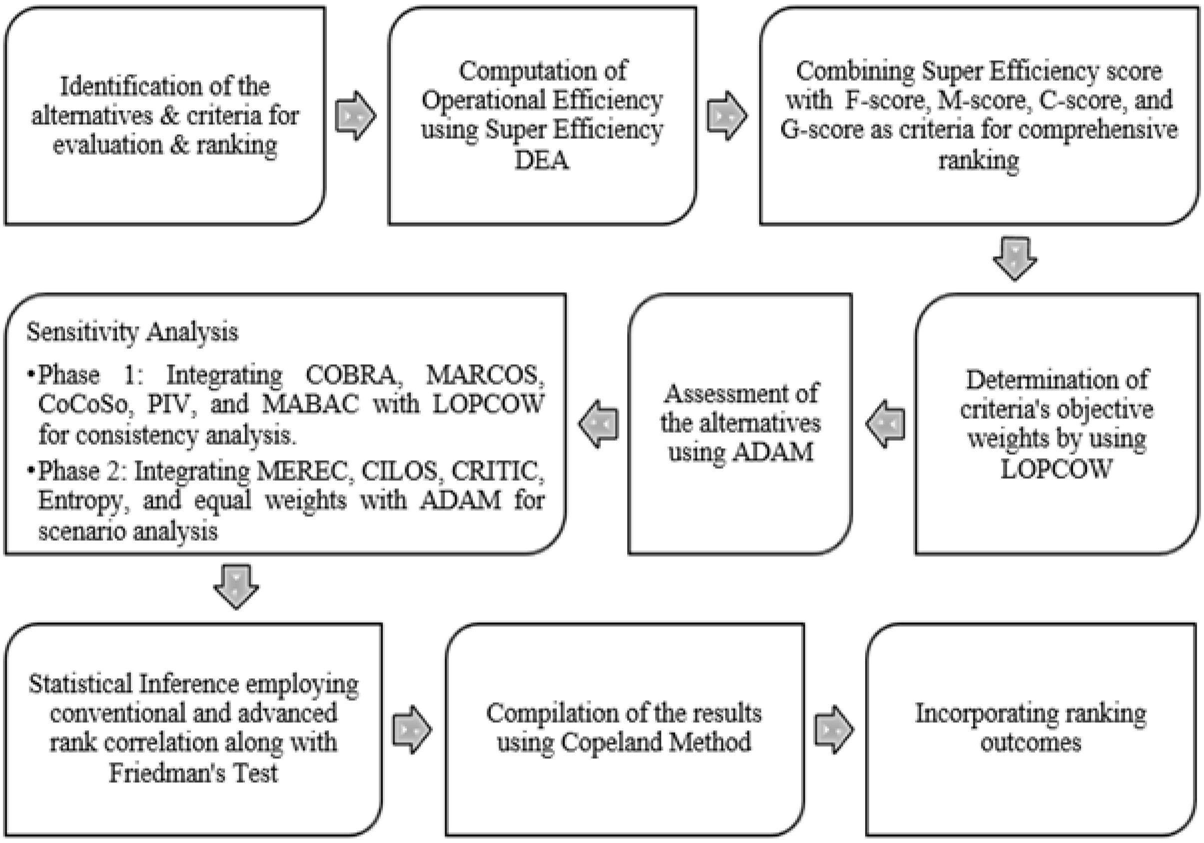

Figure 1. Methodology adopted for analysis

Source: Authors' framing

The theoretical foundation of this study is anchored in some of the renowned studies. A company becomes sustainable with the efficient management of its internal resources and capabilities. This simple yet powerful sentence is backed by the Resource-Based View (RBV) of a firm (Barney, 1991). For a capital-intensive industry like cement to be efficient, managing its operations and finances is the two important pillars. The operational capability is reflected in the efficient conversion of inputs into outputs, while the financial capability lies in value creation. Accordingly, the present study combines the two pillars for comprehensive analysis using DEA-MCDM. The Piotroski F-score, Mohanram G-score, Montier C-score, and Beneish M-score collectively provide insight into financial capability, whereas DEA captures operational efficiency. Further, from the customer's perspective, product affordability and availability are the result of smooth operations. Measures related to financial health, such as profitability, debt repayment, and job security, are the concerns of shareholders, creditors, and employees. It is, therefore, essential to align all stakeholder interests, as mentioned in the Stakeholder Theory (Freeman, 1984). Additionally, the inclusion of the Montier C-score and Beneish M-score provides a transparent view for both shareholders (Principals) and management (Agents), aligning with Agency Theory (Jensen & Meckling, 1976).

Apart from the theoretical relation, this study also has a direct connection with some of India's visionary projects and policies. The projects, such as the National Infrastructure Pipeline (NIP), Pradhan Mantri Gati Shakti, and Pradhan Mantri Awas Yojana (PMAY), are among the few initiatives taken by the Indian Government to boost connectivity, infrastructure, and economic growth. In such projects, India's cement industry plays a vital role in providing a scalable and consistent cement supply. Therefore, identifying productive and financially resilient firms is the key, which is enabled here by the application of MCDM. The study thus provides a holistic overview of India's cement industry, offering practical insights.

3.1 Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) assesses the operational efficiency level of homogeneous firms that use similar inputs to produce comparable outputs (Farrell, 1957; Charnes *et al.*, 1978; Banker *et al.*, 1984). The application of the linear programming (LP) concept allows DEA to handle complex situations with ease, even in situations involving multiple inputs and outputs. The DEA concept relies mainly on two basic models. These are the Charnes, Cooper, and Rhodes (CCR) model (Charnes *et al.*, 1978) and the Banker, Charnes, and Cooper (BCC) model (Banker *et al.*, 1984), which refer to Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS), respectively. The CCR model measures the overall technical efficiency (OTE) score, while the BCC model calculates the pure technical efficiency (PTE) score. The ratio of OTE to PTE provides the scale efficiency (SE) score. All these efficiency scores range from 0 to 1, where one indicates efficient and a score below one indicates inefficient.

The operational efficiency of a business can be assessed using either an input-oriented DEA model or an output-oriented DEA model. In an input-oriented model, the main objective is to minimise the input usage level, keeping the actual output intact. Whereas, using an output-oriented model, it is possible to maximise the existing output level without increasing the current input levels. However, in a general scenario, it is challenging to reduce the capital expenditure, because it plays a pivotal role in the growth and expansion of a business. Similarly, minimising employee benefit expenses is also cumbersome due to various employment and labour laws (Vikas & Bansal, 2019). Due to this reason, the current study employs an output-oriented DEA to assess the operational efficiency score.

3.2 Super-Radial DEA (Super-Efficiency)

Super-radial DEA is an improved version of DEA, which is one step ahead of its basic version, commonly referred to as super-efficiency. This technique is an advance as it offers extra depth by going beyond the conventional method. This model not only identifies the efficient firms but also reveals which ones are leading among the efficient ones (Andersen & Petersen, 1993). Thus, super-radial DEA will enable the firm to make more innovative use of its resources, thereby boosting productivity (Chandrasekaran & Chitnis, 2019).

3.3 Financial Efficiency

Financial efficiency provides a diagnostic report on the company's financial health status. Therefore, having a broader understanding of the financial productivity of any company is crucial. A series of financial metrics in this regard can provide a holistic view of the performance of the business. Accordingly, this study utilises a few of these metrics as proxies of financial efficiency. These are the Montier's C-score & Beneish's M-score - signals of potential financial shenanigans, and Piotroski F-score & Mohanram G-score - measures of overall financial condition.

The Montier C-score, also known as "cooking the books", acts as a warning bell to detect creative accounting in the business books. Running on six indicators, it is considered a red-flag model. If the score is zero or close to zero, there is a lower chance of accounting malpractices (Montier, 2009). Moving in the same direction, the Beneish M-score uncovers potential red flags associated with earnings manipulation (Beneish, 1999). A clean record is suggested when the score is below -2.22.

The Piotroski F-score tells the story of a company's financial strength. It breaks down the strength into nine indicators. A score ranging between 7 – 9 is always preferable from a long-term perspective (Piotroski, 2000). On the other hand, the Mohanram G-score evaluates the future expansion potential. Using 8 parameters, this metric analyses the growth prospect of the company (Mohanram, 2005).

3.4 Multi-Criteria Decision Making (MCDM)

The most challenging part of the decision-making process is selecting the best option from the available choices. It becomes even more cumbersome when the selection of alternatives depends on multiple parameters. MCDM, therefore, is a structured method used to choose the best among available alternatives, while considering multiple parameters (Majumder & Saha, 2016; Zeleny, 1998). With the increasing real-life problems that are common but complex, this particular approach has gathered significant attention (Kurian *et al.*, 2020; Fodor & Roubens, 1994). Further, to counter the diversities of decision-making problems involving conflicting and multiple parameters, various MCDM techniques have been introduced (Sahoo & Goswami, 2023). The key advantage of the MCDM is that it encourages comparing alternatives against one another, instead of examining them in isolation. However, any MCDM framework begins with determining the importance of the criteria (Wu, 2011). The current study determined the relative weight of each criterion using an advanced objective weight determination method called LOPCOW

(LOgarithmic Percentage Change-driven Objective Weighting), and moved in the same direction. It is preferred here because this method not only can adjust for differences in dataset size, but also enables easy handling of both negative and positive data (Ecer & Pamucar, 2022). Eventually, the ranking of the companies is performed using the ADAM (Axial Distance-based Aggregated Measurement) technique, which utilises the volume of complex polyhedra – an advanced geometry-based ranking method (Krstić *et al.*, 2023).

3.5 Copeland Method

With the periodic evolution of the MCDM framework, various techniques under multi-criteria decision-making analysis have emerged. However, one of the debatable arguments against MCDM is the variation in how each technique processes data and determines final ranks. Depending upon the selection of MCDM techniques, the ranking results may vary. Therefore, to address such an issue, the Copeland method plays a crucial role (Zavadskas *et al.*, 2017), which builds on the upgraded version of the Baroda count (1781) (Dortaj *et al.*, 2020). The Copeland method is a rank aggregation technique designed to combine multiple rankings into a consolidated rank (Wu, 2011).

3.6 Data & Variables

The data for the study are collected from various sources. Among these sources, the company's annual report and other documents are primarily used. The reports of the Asset Management Companies (AMCs) and Credit Rating Agencies (CRAs) are also taken into account. For DEA and super-efficiency, data are extracted from the annual report. Further, various AMC and CRA reports are also used to collect information on the Piotroski F-score, Mohanram G-score, Montier C-score, and Beneish M-score. Table 1 represents the list of variables used in this study.

Table 1. List of Variables & Criteria

Variables for DEA & Super-radial DEA (Super-efficiency)	
INPUT VARIABLES	**OUTPUT VARIABLES**
• Raw Material Cost	• Operating Revenues
• Power & Fuel Cost	• Operating Profit
• Employee Benefit Cost	• Operating Cash Flows
• Capital Expenditure	
Criteria for Multi-Criteria Decision Making	
• Super-efficiency Score	• Montier C-score
• Piotroski F-score	• Beneish M-score
• Mohanram G-score	

Source: Authors' compilations

Table 2. Correlation among the variables

Output Variables➡ **Input Variables⬇**	**Operating Revenue**	**Operating Profit**	**Operating Cash Flow**
Raw Material Cost	0.9645	0.9169	0.8327
Power & Fuel Cost	0.9946	0.9623	0.8844
Employee Benefit Cost	0.9906	0.9408	0.8783
Capital Expenditure	0.9495	0.9262	0.8331

Source: Authors' computations

4. Results

4.1. Correlation Analysis of Variables

Correlation analysis quantifies the association between output and input variables. Table 2 presents the correlation coefficients among the variables. It shows a strong and positive connection between the output and input variables.

4.2. Data Envelopment Analysis (DEA)

The proxies for the operational efficiency score – Scale Efficiency (SE), Pure Technical Efficiency (PTE), and Overall Technical Efficiency (OTE) scores are derived by engaging three output variables (operating revenues, operating profit, and operating cash flow) in conjunction with four input variables (raw material cost, power & fuel cost, employee benefit cost, and capital expenditure), adhering to the two thumb rules provided by Cooper et al. (2007) regarding sample size determination.

The efficiency scores for all 28 cement companies are computed using the Charnes, Cooper, and Rhodes (CCR) model for the OTE score and the Banker, Charnes, and Cooper (BCC) model for the PTE score. The SE score is worked out by dividing the OTE score by the PTE score. PTE indicates how well an entity is "doing things right" (making the most of its resources given its current size), while SE assesses if it is "doing things at the right scale". OTE combines both aspects for a holistic evaluation of performance. Table 3 exhibits an overview of efficiency scores.

Table 3. Overview of Efficiency Scores

S. No.	Companies / DMUs	OTE (CCR, CRS)	PTE (BCC, VRS)	SE (OTE ÷ PTE)
1	Ultratech Cement	1	1	1
2	Ambuja Cement	1	1	1
3	Shree Cement	1	1	1
4	ACC Ltd.	0.7950	0.9190	0.8650
5	JK Cements	1	1	1
6	The Ramco Cement	0.8512	0.9414	0.9042
7	Birla Corporation Ltd	0.8626	0.9002	0.9582
8	Nuvoco Vistas	0.9580	1	0.9580
9	JK Lakshmi Cement	1	1	1
10	Prism Johnson Ltd	0.9211	1	0.9211
11	Star Cement	1	1	1
12	India Cements	0.6825	1	0.68249
13	Kesoram Industries Ltd	1	1	1
14	Heidelberg Cement	1	1	1
15	Orient Cement	0.9211	0.9481	0.9715
16	Sagar Cements Ltd.	0.8822	0.8893	0.9920
17	Sanghi Cement	1	1	1
18	KCP Ltd.	0.9900	1	0.9900
19	Mangalam Cement	0.6348	0.6548	0.9695
20	Digvijay Cement	1	1	1
21	Saurashtra Cement Ltd.	0.7581	0.7602	0.9973
22	NCL Industries Ltd.	1	1	1
23	Deccan Cements Ltd.	1	1	1
24	Anjani Portland Cement Ltd.	1	1	1
25	Keshav Cement & Infra Ltd.	1	1	1
26	Kakatiya Cement	0.5792	0.5824	0.9944
27	Barak Valley Cements Ltd.	1	1	1
28	Keerthi Industries	0.5646	1	0.5646

Source: Authors' computations

Using the CRS-DEA model, 15 out of 28 (53.57%) companies emerge as overall technically efficient DMUs, with an average OTE score of 0.9072. Similarly, working out VRS-DEA, 20 (71.43%) companies emerge as pure technically efficient DMUs, with an average PTE score of 0.9498. Accordingly, 15 DMUs are scale-efficient. PTE illustrates managerial efficacy, whereas SE signifies the operational scale proficiency of the business (Vikas & Bansal, 2019). Table 4 elucidates the summary statistics of efficiency scores.

Table 4. Summary Statistics Table of OTE, PTE & SE Scores

Efficiency Scores	No. of Efficient DMUs	(%) of Efficient DMUs	Mean	SD
OTE	15	53.57	0.9072	0.1400
PTE	20	71.43	0.9498	0.1081
SE	15	53.57	0.9560	0.1010

Source: Authors' computations

A DEA application is always able to distinguish between efficient and inefficient units. It also yields a specific value for the lag variables for the inefficient DMUs. The output lags indicate an inadequate outcome, while the input lags represent underutilised input variables. Therefore, by optimally monitoring the lag resources, an inefficient company can operate on the efficient frontier curve. In the short term, DMUs operate within the variable returns to scale (VRS) framework. However, DMUs have ample time to adjust their operational scale in the long run, aiming to operate at constant returns to scale (CRS), which signifies minimal input utilisation and optimal average output production. Against this backdrop, Table 5 and Table 6 demonstrate the actual and desired levels of input and output variables, respectively, for the 13 underperforming cement firms employing the CRS-DEA model, thereby attending to the additional objective (i) of the study.

Table 5. Actual & Desired Input Levels of Inefficient Companies (in Crores)

S. No.	Companies / DMUs	Actual Input Levels				Desired Input Levels			
		Raw Mat. Cost	Pow. & Fuel	Empl. Cost	Cap. Exp.	Raw Mat. Cost	Pow. & Fuel	Empl. Cost	Cap. Exp.
1	ACC Ltd.	3877.21	4796.28	824.15	1936	3877.21	4796.28	780.51	1556.74
2	Ramco Cement	1342.97	2661.60	460	1765	1342.97	2661.60	460	1359.86
3	Birla Corp	1080.25	1607.09	361.01	253	1080.25	1607.09	262.02	253
4	Nuvoco Vistas	2423.24	2013.36	481.45	353	2423.24	2013.36	465.33	353
5	Prism Johnson	2817.07	1316.47	523.41	306	2606.08	1316.47	360.71	306
6	India Cements	936.84	2427.38	358.32	144	936.84	2427.38	348.96	144
7	Orient Cement	386.49	928.08	166.10	130	386.49	928.08	135.30	130
8	Sagar Cements	361.82	743.90	83.04	74	209.09	681.21	83.04	74
9	KCP Ltd.	340.37	693.18	88.08	25	240.82	671.11	88.08	25
10	Mangalam Cement	327.09	633.49	113.09	127	327.09	633.49	81.64	127
11	Saurashtra Cement	248.81	760.95	97.82	39	228.62	760.95	97.82	39
12	Kakatiya Cement	45.51	79.48	19.37	1.29	45.51	79.48	16.95	1.29
13	Keerthi Industries	24.85	123.14	22.77	35.36	24.85	123.14	17.59	35.36

Source: Authors' computations

The overall cement industry has efficiently optimised raw material utilisation, with few anomalies. Power and fuel costs have been managed effectively across the sector, except for Sagar Cements and KCP Ltd. In terms of capital investment expenditure, only ACC Ltd. and Ramco Cement display inefficiencies in making the most of it. However, a majority of inefficient companies require thorough monitoring, especially concerning expenditures related to employee benefits. As a result, the actual input levels of all 13 companies do not align with the desired input levels, making them inefficient decision-making units (DMUs).

The performance of any business is directly and strongly interconnected to its operating revenue, operating profit, and cash flow from operations. In this regard, the pivotal aspect is the effective management and periodic review of these performance indicators. However, for inefficient companies, the current output level falls short of the desired output level. Among all the inefficient DMUs, mainly Keerthi Ind. Ltd., Kakatiya Cement, Mangalam Cement, India Cements, and Saurashtra Cement have to increase their operating revenue by 43.54%, 42.22%, 36.52%, 31.75%, and 24.19%, respectively. Apart from this, companies must substantially improve their operating profit and operating cash flow to remain competitive in the race for efficient decision-making units (DMUs).

Table 6. Actual & Desired Output Levels of Inefficient Companies (in Crores)

S. No.	Companies / DMUs	Actual Output Levels			Desired Output Levels		
		Operating Revenue	Operating Profit	Operating Cash Flow	Operating Revenue	Operating Profit	Operating Cash Flow
1	ACC Ltd.	17419	792	-1671.42	20990.72	1216.22	2207.37
2	Ramco Cement	8135	679	1405	9345.19	899.97	1614.01
3	Birla Corporation	5441	79	209.89	6188.69	399.14	585.70
4	Nuvoco Vistas	8582	124	1022.96	8942.42	874.61	1065.92
5	Prism Johnson	6711	65	626.20	7240.62	844.00	988.83
6	India Cements	5381	-386	-10.62	7089.52	575.95	560.78
7	Orient Cement	2938	218	111	3169.92	235.21	327.02
8	Sagar Cements	1910	88	127	2135.08	154.71	179.77
9	KCP Ltd.	1665	-47	91.75	1681.71	83.24	92.67
10	Mangalam Cement	1802	79	138.67	2460.02	137.21	271.45
11	Saurashtra Cement	1645	-33	21.26	2042.87	140.07	137.06
12	Kakatiya Cement	154	-21	-37.94	219.02	18.18	27.72
13	Keerthi Industries	241	-9	6.26	345.93	9.39	35

Source: Authors' computations

Although DEA aids in distinguishing between efficient and inefficient DMUs, as shown in Table 3, it is unable to provide a clear picture for efficient companies in particular. This is because traditional DEA always assigns a score of 1 to efficient units, thereby hindering cross-comparison. However, to overcome this drawback, the super-radial (CCR, CRS) DEA methodology is deployed to compute the super-efficiency score.

4.3 Super-Radial DEA (Super-Efficiency)

Due to the enhanced determination ability of the super-radial DEA (super-efficiency), the ranking of cement firms has become more prominent. Table 7 highlights the companies' OTE, super-efficiency score, and ranking outcome to address the additional objective (ii) of the study. Figure 2 depicts the pictorial view of companies' super-efficiency score.

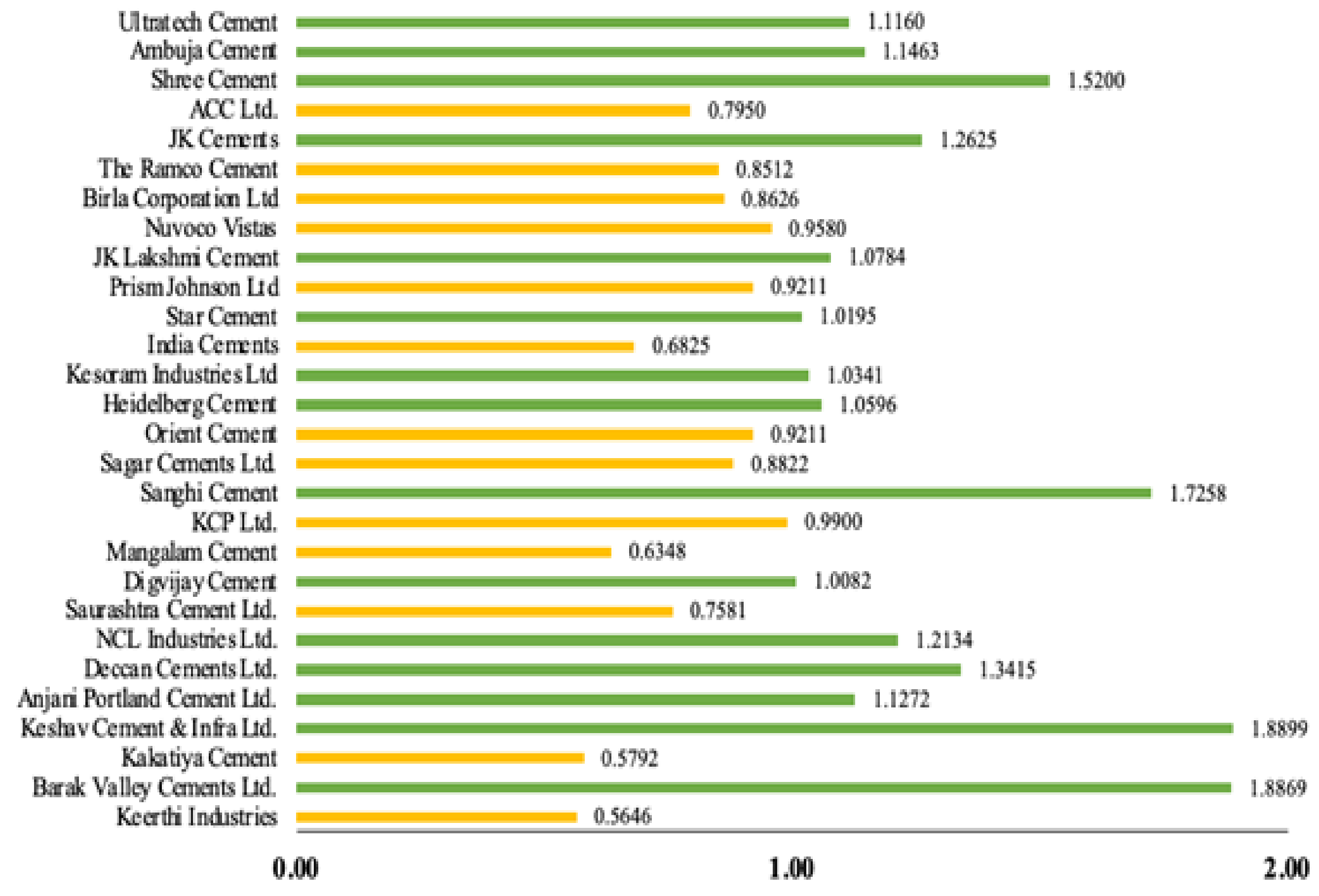

Figure 2. Super Efficiency Scores

Source: Authors' computations

Table 7. Overall Technical Efficiency and Super-efficiency Scores & Ranking

S. No.	Companies / DMUs	OTE (CCR, CRS)	Rank	Super-Radial (CCR, CRS)	Rank
1	Ultratech Cement	1	1	1.1160	10
2	Ambuja Cement	1	1	1.1463	8
3	Shree Cement	1	1	1.5200	4
4	ACC Ltd.	0.7950	23	0.7950	23
5	JK Cements	1	1	1.2625	6
6	The Ramco Cement	0.8512	22	0.8512	22
7	Birla Corporation Ltd	0.8626	21	0.8626	21
8	Nuvoco Vistas	0.9580	17	0.9580	17
9	JK Lakshmi Cement	1	1	1.0784	11
10	Prism Johnson Ltd	0.9211	18	0.9211	18
11	Star Cement	1	1	1.0195	14
12	India Cements	0.6825	25	0.6825	25
13	Kesoram Industries Ltd	1	1	1.0341	13
14	Heidelberg Cement	1	1	1.0596	12
15	Orient Cement	0.9211	19	0.9211	19
16	Sagar Cements Ltd.	0.8822	20	0.8822	20
17	Sanghi Cement	1	1	1.7258	3
18	KCP Ltd.	0.9900	16	0.9900	16

19	Mangalam Cement	0.6348	26	0.6348	26
20	Digvijay Cement	1	1	1.0082	15
21	Saurashtra Cement Ltd.	0.7581	24	0.7581	24
22	NCL Industries Ltd.	1	1	1.2134	7
23	Deccan Cements Ltd.	1	1	1.3415	5
24	Anjani Portland Cement Ltd.	1	1	1.1272	9
25	Keshav Cement & Infra Ltd.	1	1	1.8899	1
26	Kakatiya Cement	0.5792	27	0.5792	27
27	Barak Valley Cements Ltd.	1	1	1.8869	2
28	Keerthi Industries	0.5646	28	0.5646	28

Source: Authors' computations

Among the efficient decision-making units acquired from the CCR model, Keshav Cement & Infra Ltd. has been recognised as the most proficient firm. It is noteworthy to mention that the big players in the cement sector, including Ambuja Cement, Shree Cement, and Ultratech Cement, are not among the top three contenders in terms of operational efficiency. Moreover, it is fascinating to emphasise that 60% of the operationally efficient cement firms are micro and small-cap companies, implying that small players are comparatively more operationally efficient than the giants in 2022–23. Therefore, owing to this eyebrow-raising scenario and to more thoroughly assess and appraise the cement companies, financial efficiency metrics – Piotroski F-score, Mohanram G-score, Montier C-score, and Beneish M-score are utilised, in conjunction with the super-efficiency score – an indicator of operational efficiency, as parameters for employing multi-criteria analysis.

4.4 Correlation Coefficients of Criteria

The correlation coefficient illustrates the linkage and relationship between the variables. Table 8 exhibits the correlation coefficients among these four criteria, along with the super-efficiency score.

Table 8. Correlation Matrix among the Criteria

Criteria	Piotroski F-Score	Beneish M-Score	Montier C-Score	Mohanram G-Score	Super-efficiency Score
Piotroski F-Score	1				
Beneish M-Score	-0.3656	1			
Montier C-Score	-0.2677	0.2475	1		
Mohanram G-Score	0.6707	-0.3160	-0.1024	1	
Super-efficiency Score	0.1667	-0.4849	-0.0146	0.0779	1

Source: Authors' computations

4.5 Criterion Weights

Determining the relative importance of the parameters is a prerequisite and paramount for the application of MCDM techniques. Table 9 demonstrates the weights of all five criteria used to rank the 28 Indian cement companies for the year 2022–23.

Table 9. Criterion weight based on LOPCOW

Weight	Piotroski F-Score	Beneish M-Score	Montier C-Score	Mohanram G-Score	Super-efficiency Score
LOPCOW	0.1842	0.2885	0.2144	0.1870	0.1259

Source: Authors' computations

4.6. Ranking Outcome under LOPCOW-ADAM Technique

LOPCOW – an objective weight determining technique, alongside ADAM – an outranking method, combined to obtain the ranking results of cement companies. Table 10 exhibits the rank of the DMUs based on the LOPCOW-ADAM technique.

Table 10. Ranking based on integrated LOPCOW-ADAM approach

S. No.	Companies / DMUs	Volume	Rank as per LOPCOW-ADAM
1	Ultratech Cement	0.0518	3
2	Ambuja Cement	0.0349	13
3	Shree Cement	0.0419	9
4	ACC Ltd.	0.0190	23
5	JK Cements	0.0393	10
6	The Ramco Cement	0.0368	12
7	Birla Corporation Ltd	0.0491	4
8	Nuvoco Vistas	0.0249	19
9	JK Lakshmi Cement	0.0326	16
10	Prism Johnson Ltd	0.0469	5
11	Star Cement	0.0437	8
12	India Cements	0.0231	21
13	Kesoram Industries Ltd	0.0169	26
14	Heidelberg Cement	0.0461	6
15	Orient Cement	0.0292	17
16	Sagar Cements Ltd.	0.0371	11
17	Sanghi Cement	0.0248	20
18	KCP Ltd.	0.0255	18
19	Mangalam Cement	0.0649	1
20	Digvijay Cement	0.0459	7
21	Saurashtra Cement Ltd.	0.0154	27
22	NCL Industries Ltd.	0.0328	15
23	Deccan Cements Ltd.	0.0223	22
24	Anjani Portland Cement Ltd.	0.0170	25
25	Keshav Cement & Infra Ltd.	0.0330	14
26	Kakatiya Cement	0.0040	28
27	Barak Valley Cements Ltd.	0.0551	2
28	Keerthi Industries	0.0173	24

Source: Authors' computations

4.7. Sensitivity Analysis

It is evident from Table 10 that Mangalam Cement has emerged as the top-ranked cement company for the year 2022–23, followed by Barak Valley Cements Ltd. and Ultratech Cement. However, similarity in the companies' performance may alter ranks across the MCDM techniques (Varmazyar et al., 2016). This can lead to an inconsistency issue (Hobbs et al., 1992). Therefore, to ensure robustness, this shortcoming has been addressed through a two-phase sensitivity analysis.

For first-phase consistency analysis, the LOPCOW method is combined with other MCDM techniques, such as COBRA (COmprehensive Distance Based Ranking) (Krstić *et al.,* 2022), MARCOS (Measurement Alternatives and Ranking according to COmpromise Solution) (Stević *et al.,* 2020), CoCoSo (COmbined COmpromise SOlution) (Yazdani *et al.,* 2019), PIV (Proximity Indexed Value) (Khan et al., 2019), and MABAC (Multi-Attributive Border Approximation area Comparison) (Pamučar & Ćirović, 2015). Parallelly, equal weights of the criteria along with other objective weight determination methods like MEREC (Keshavarz-Ghorabaee *et al.,* 2021), CILOS (Zavadskas & Podvezko, 2016), CRITIC (Diakoulaki *et al.,* 1995), and Entropy (Shannon, 1948; Zeleny, 1982), are also considered. Accordingly, for the second-phase scenario analysis, the ADAM technique is combined with the above methods.

4.7.1. Consistency Analysis: Outcomes under various MCDM methods

The companies under study are ranked based on the relative significance (weight) of the criterion, using the ADAM method. To validate the results obtained using the ADAM method, comparisons are made with other established MCDM techniques like COBRA, CoCoSo, MARCOS, PIV, and MABAC. Table 11 displays the values obtained by these methods. Figure 3 represents the pictorial view of consistency analysis.

Table 11. Ranking based on integrated LOPCOW and other MCDM methods

S. No.	Companies / DMUs	LOPCOW-ADAM	LOPCOW-COBRA	LOPCOW-MARCOS	LOPCOW-CoCoSo	LOPCOW-PIV	LOPCOW-MABAC
1	Ultratech Cement	3	4	4	3	3	3
2	Ambuja Cement	13	15	17	16	16	16
3	Shree Cement	9	8	8	9	9	9
4	ACC Ltd.	23	26	26	25	26	26
5	JK Cements	10	12	12	10	12	10
6	Ramco Cement	12	17	15	15	14	15
7	Birla Corporation	4	7	6	5	4	5
8	Nuvoco Vistas	19	18	18	19	19	19
9	JK Lakshmi	16	13	16	17	17	17
10	Prism Johnson	5	5	7	6	5	6
11	Star Cement	8	2	5	4	6	4
12	India Cements	21	25	25	21	21	23
13	Kesoram Industries	26	22	23	22	23	24
14	Heidelberg Cement	6	3	3	2	2	2
15	Orient Cement	17	19	19	18	18	18
16	Sagar Cements	11	14	11	11	11	11
17	Sanghi Cement	20	10	14	14	15	14
18	KCP Ltd.	18	24	21	20	20	20
19	Mangalam Cement	1	11	2	8	7	8
20	Digvijay Cement	7	6	9	7	8	7
21	Saurashtra Cement	27	27	27	27	27	27
22	NCL Industries	15	9	10	13	13	13
23	Deccan Cements	22	20	20	24	24	22
24	Anjani Portland	25	23	22	23	22	21

25	Keshav Cement	14	16	13	12	10	12
26	Kakatiya Cement	28	28	28	28	28	28
27	Barak Valley	2	1	1	1	1	1
28	Keerthi Industries	24	21	24	26	25	25

Source: Authors' computations

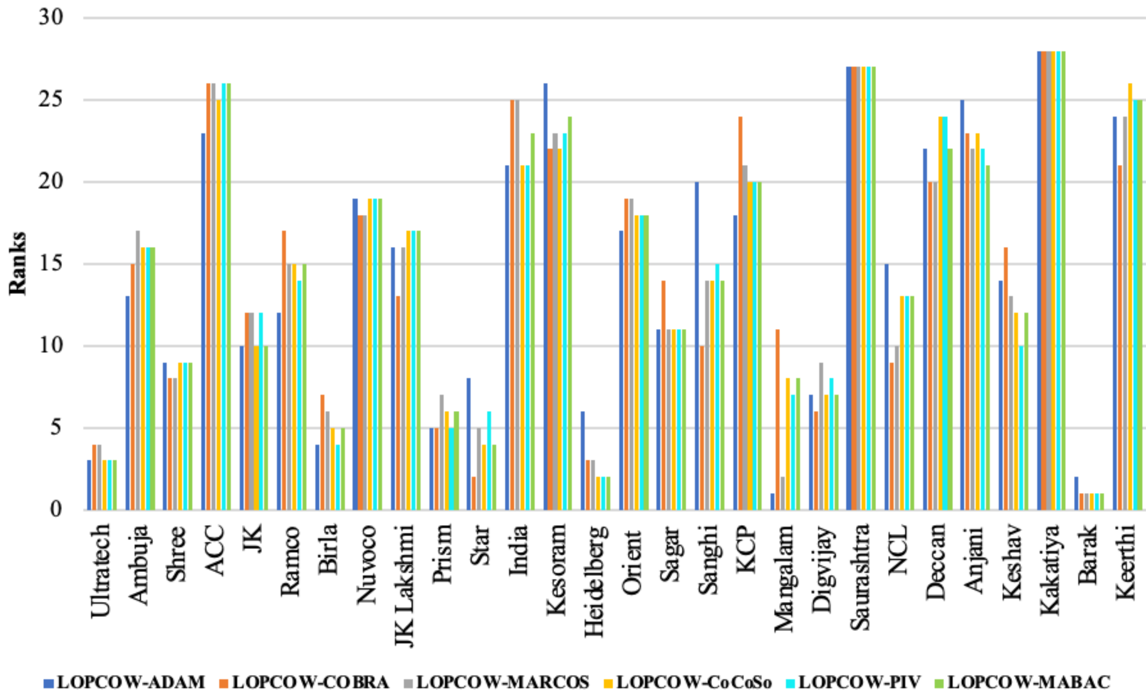

Figure 3. Comparative Rankings under Consistency Analysis

Source: Authors' computations

It is evident from Table 11 that although there is a difference in the ranking outcomes of the DMUs under various MCDM methods, the results are relatively close. This deviation in the outcome is attributable to variations in the computation methodology, such as the data normalisation technique used by these MCDM methods. Nevertheless, on such occasions, reliability in the outcome is crucial.

Table 12(a). Rank Correlation Coefficients

Test	MCDM Methods	LOPCOW-COBRA	LOPCOW-MARCOS	LOPCOW-CoCoSo	LOPCOW-PIV	LOPCOW-MABAC
Spearman	LOPCOW-ADAM	0.8774*	0.9491*	0.9496*	0.9568*	0.9491*
Kendall	LOPCOW-ADAM	0.7143*	0.8148*	0.8360*	0.8413*	0.8307*
* **represents significance at 1% level.**						

Source: Authors' computations

Therefore, to overcome this challenge, conventional correlation analyses – Spearman's Rank correlation (r_S) and Kendall correlation (τ), followed by advanced correlation analyses – Weighted Spearman's Rank correlation (r_W) and Rank Similarity correlation (W_S) are performed, in conjunction with Friedman's test. These analyses will establish the connection between outcomes acquired under various MCDM methods. Tables 12-14 present the results of the rank correlation analyses, and Table 15 highlights the result of Friedman's test, all of which reinforce the reliability of the outcomes.

Table 13. Weighted Spearman's Rank Correlation Coefficients (r_w)

	LOPCOW-ADAM	LOPCOW-COBRA	LOPCOW-MARCOS	LOPCOW-CoCoSo	LOPCOW-PIV	LOPCOW-MABAC
LOPCOW-ADAM	1					
LOPCOW-COBRA	0.8641	1				
LOPCOW-MARCOS	0.9530	0.9378	1			
LOPCOW-CoCoSo	0.9416	0.9569	0.9692	1		
LOPCOW-PIV	0.9519	0.9372	0.9712	0.9928	1	
LOPCOW-MABAC	0.9411	0.9597	0.9724	0.9979	0.9920	1

Source: Authors' computations

The correlation coefficients under both the Spearman (r_s) and Kendall (τ) rank correlation tests suggest a strong and significant association between the outcomes under different MCDM methods. Further, Weighted Spearman's Rank correlation coefficients (r_w) (Dancelli *et al.*, 2013), and Rank Similarity correlation coefficients (WS) (Sałabun & Urbaniak, 2020) are also obtained, to address the shortcomings of assigning "equal emphasis" on all ranks by these traditional rank correlation measures.

Under Weighted Spearman's Rank Correlation (r_w), more flexibility and a detailed understanding of rank agreement (or disagreement) in specific parts of the ranking is possible (Dancelli *et al.*, 2013). The result highlights a deep connection among ranking outcomes across various MCDM methods.

Table 14. Rank Similarity Correlation Coefficients (WS)

	LOPCOW-ADAM	LOPCOW-COBRA	LOPCOW-MARCOS	LOPCOW-CoCoSo	LOPCOW-PIV	LOPCOW-MABAC
LOPCOW-ADAM	1					
LOPCOW-COBRA	0.7883	1				
LOPCOW-MARCOS	0.9552	0.9653	1			
LOPCOW-CoCoSo	0.8531	0.9694	0.9317	1		
LOPCOW-PIV	0.8755	0.9503	0.9403	0.9920	1	
LOPCOW-MABAC	0.8531	0.9694	0.9317	0.9999	0.9939	1

Source: Authors' computations

Rank Similarity Correlation (*WS*) analyses the ranking similarities when top positions hold disproportionately higher significance (Sałabun & Urbaniak, 2020). The results of the correlation coefficients show a deep connection among ranking outcomes across various MCDM methods.

Table 15. Friedman's Test

Chi-squared statistic	1.1640
***p*-Value**	0.9483

Source: Authors' computations

Friedman's test helps to compare and understand the variation in ranking outcomes that occur when different MCDM techniques are applied to an identical decision-making situation. Here, the computed p-value is more than the significance threshold level of 0.01. This implies that there are no statistically significant disparities between average rankings across various MCDM methods.

4.7.2 SCENARIO ANALYSIS: Outcomes under various objective weight techniques

The LOPCOW technique assigns weights (as a % of relative importance) to the criteria, which serve as parameters for ranking the alternatives. In order to assess the reliability of the outcomes under the LOPCOW technique, comparisons with other popular objective weight determination techniques, like MEREC (MEthod based on the Removal Effects of Criteria), CILOS (Criterion Impact LOSs), CRITIC (CRiteria Importance through Intercriteria Correlation), and Entropy, are done along with equal weights. Table 16 displays the values obtained using those techniques. Figure 4 represents the pictorial view of scenario analysis.

Table 16. Ranking based on various objective weight determination techniques integrated with ADAM

S. No.	Companies / DMUs	LOPCOW-ADAM	MEREC-ADAM	CILOS-ADAM	CRITIC-ADAM	Entropy-ADAM	Equal-Weight
1	Ultratech Cement	3	1	1	3	3	3
2	Ambuja Cement	13	13	10	14	14	14
3	Shree Cement	9	7	4	7	9	2
4	ACC Ltd.	23	25	25	23	24	25
5	JK Cements	10	11	9	10	11	10
6	Ramco Cement	12	14	16	13	13	18
7	Birla Corporation	4	5	6	4	5	8
8	Nuvoco Vistas	19	18	19	19	20	19
9	JK Lakshmi	16	12	11	15	16	15
10	Prism Johnson	5	6	8	5	6	7
11	Star Cement	8	2	3	9	10	4
12	India Cements	21	21	21	22	23	23
13	Kesoram Industries	26	24	24	24	25	22
14	Heidelberg Cement	6	8	7	6	4	6
15	Orient Cement	17	16	15	17	17	20
16	Sagar Cements	11	15	14	11	12	17
17	Sanghi Cement	20	20	20	20	18	13
18	KCP Ltd.	18	23	22	21	19	21
19	Mangalam Cement	1	3	13	1	2	9
20	Digvijay Cement	7	4	5	8	8	5

21	Saurashtra Cement	27	26	27	27	26	27
22	NCL Industries	15	10	12	12	15	11
23	Deccan Cements	22	17	18	18	22	16
24	Anjani Portland	25	27	23	25	21	24
25	Keshav Cement	14	19	17	16	7	12
26	Kakatiya Cement	28	28	28	28	28	28
27	Barak Valley	2	9	2	2	1	1
28	Keerthi Industries	24	22	26	26	27	26

Source: Authors' computations

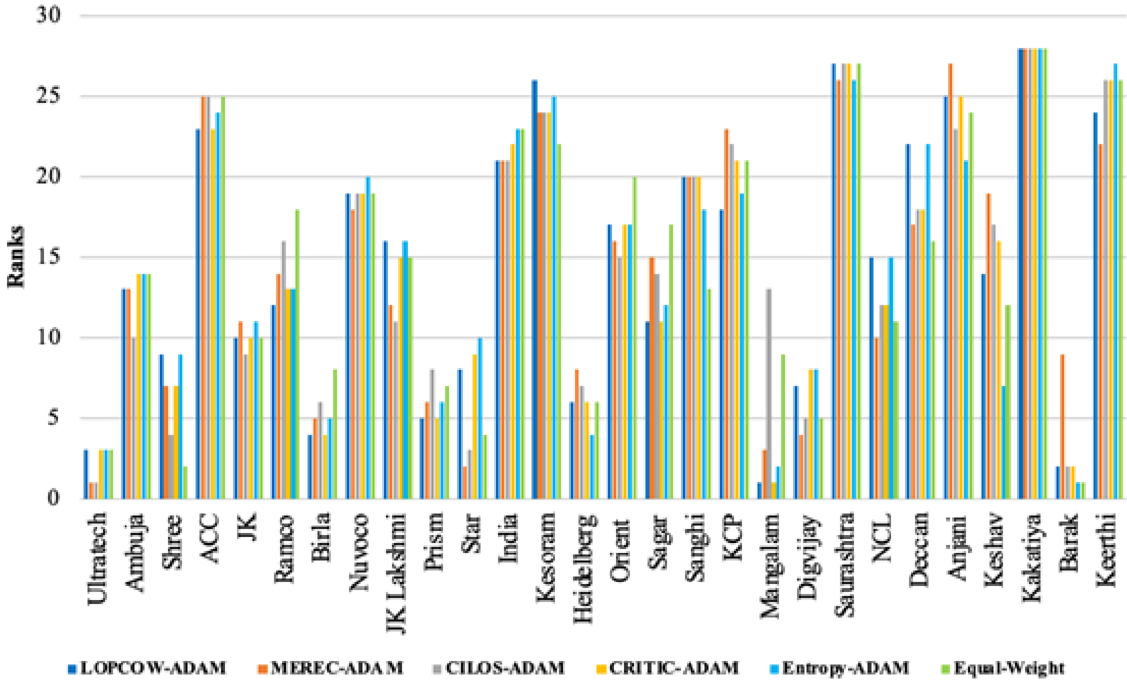

Figure 4. Comparative Rankings under Scenario Analysis

Source: Authors' computations

Table 15 demonstrates that, despite deviations in the firms' rank under various objective weight scenarios, the outcomes are relatively close.

This discrepancy is a consequence of the diverse computational methodologies of various techniques. However, in such a situation, the consistency of the result is a pivotal factor. Therefore, this study engages Spearman's Rank correlation (r_s), Kendall correlation (τ), Weighted Spearman's Rank correlation (r_w), Rank Similarity correlation (WS), and Friedman's test to ascertain the relationship between outcomes obtained under different scenarios. Tables 17-19 display the results of the rank correlation analyses, and Table 20 exhibits the result of Friedman's test.

The correlation coefficients obtained from both the Spearman and Kendall rank correlation tests indicate a strong and significant association between the outcomes under different scenarios, as depicted by various object weight determination techniques. However, to overcome the drawbacks of these conventional rank correlation measures, Weighted Spearman's Rank correlation coefficients (r_w) (Dancelli *et al.,* 2013) and Rank Similarity correlation coefficients (*WS*) (Sałabun & Urbaniak, 2020) are derived.

Table 17. Rank Correlation Analysis

Test	MCDM Methods	MEREC-ADAM	CILOS-ADAM	CRITIC-ADAM	Entropy-ADAM	Equal-Weight
Spearman	LOPCOW-ADAM	0.9267*	0.9053*	0.9847*	0.9715*	0.8960*
Kendall	LOPCOW-ADAM	0.7672*	0.7513*	0.9206*	0.8942*	0.7037*
* represents significance at 1% level.						

Source: Authors' computations

Table 18. Weighted Spearman's Rank Correlation Coefficients (r_w)

	LOPCOW-ADAM	MEREC-ADAM	CILOS-ADAM	CRITIC-ADAM	Entropy-ADAM	Equal-Weight
LOPCOW-ADAM	1					
MEREC-ADAM	0.9148	1				
CILOS-ADAM	0.8780	0.9194	1			
CRITIC-ADAM	0.9880	0.9278	0.8908	1		
Entropy-ADAM	0.9717	0.8513	0.8473	0.9574	1	
Equal-Weight	0.8805	0.8935	0.9472	0.8991	0.8858	1

Source: Authors' computations

Weighted Spearman's Rank Correlation coefficients (r_w) across all scenarios exceed 0.84, representing a strong connection between the ranking outcomes derived from different objective weight determination techniques in MCDM.

Table 19. Rank Similarity Correlation Coefficients (WS)

	LOPCOW-ADAM	MEREC-ADAM	CILOS-ADAM	CRITIC-ADAM	Entropy-ADAM	Equal-Weight
LOPCOW-ADAM	1					
MEREC-ADAM	0.8775	1				
CILOS-ADAM	0.7553	0.9328	1			
CRITIC-ADAM	0.9992	0.8719	0.9181	1		
Entropy-ADAM	0.9656	0.8679	0.8983	0.9655	1	
Equal-Weight	0.8266	0.9031	0.9406	0.8259	0.9190	1

Source: Authors' computations

Rank Similarity Correlation coefficients (*WS*) across all scenarios exceed 0.75, highlighting a deep association among ranking outcomes derived under different objective weight determination techniques of MCDM.

Table 20. Friedman's Test

Chi-squared statistic	1.9988
***p*-Value**	0.8493

Source: Authors' computations

The p-value under Friedman's test is greater than the 0.01 significance threshold. This result shows no statistically significant disparities between average rankings across various objective weight determination techniques of MCDM. Therefore, it indicates that the ranking outcome under integrated LOPCOW-ADAM is consistent with alternate scenarios. Hence, the findings of the sensitivity analysis – consistency and scenario analyses address the additional objective (iii) of the study.

4.8 Overall Ranking of the Companies

The Copeland method is a rank aggregation technique used to combine multiple ranking results obtained under various MCDM techniques and provides a single consolidated rank. Eventually, the study applies the Copeland method to the multiple ranking outcomes in Table 11 to assign a comprehensive rank. Table 21 summarises the aggregate ranking outcome of Indian cement companies for the year 2022–23, which completes the primary aim of the study. Figure 5 highlights the final ranking of companies.

Table 21. Consolidated Ranking based on the Copeland Method

S. No.	Companies / DMUs	WINS (BORDA COUNT)	LOSES	FINAL SCORE	RANK
1	Ultratech Cement	25	2	23	3
2	Ambuja Cement	12	15	-3	16
3	Shree Cement	19	8	11	9
4	ACC Ltd.	2	25	-23	26
5	JK Cements	18	9	9	10
6	The Ramco Cement	13	14	-1	15
7	Birla Corporation Ltd.	23	4	19	5
8	Nuvoco Vistas	9	18	-9	19
9	JK Lakshmi Cement	11	16	-5	17
10	Prism Johnson Ltd.	22	5	17	6
11	Star Cement	24	3	21	4
12	India Cements	6	21	-15	21
13	Kesoram Industries Ltd.	4	23	-19	24
14	Heidelberg Cement	26	1	25	2
15	Orient Cement	10	17	-7	18
16	Sagar Cements Ltd.	17	10	7	11
17	Sanghi Cement	14	13	1	14
18	KCP Ltd.	8	19	-11	20
19	Mangalam Cement	20.5	6.5	14	7
20	Digvijay Cement	20.5	6.5	14	7
21	Saurashtra Cement Ltd.	1	26	-25	27
22	NCL Industries Ltd.	15	12	3	13
23	Deccan Cements Ltd.	6	21	-15	21
24	Anjani Portland Cement Ltd.	6	21	-15	21
25	Keshav Cement & Infra Ltd.	16	11	5	12
26	Kakatiya Cement	0	27	-27	28

27	Barak Valley Cements Ltd.	27	0	27	1
28	Keerthi Industries	3	24	-21	25

Source: Authors' computations

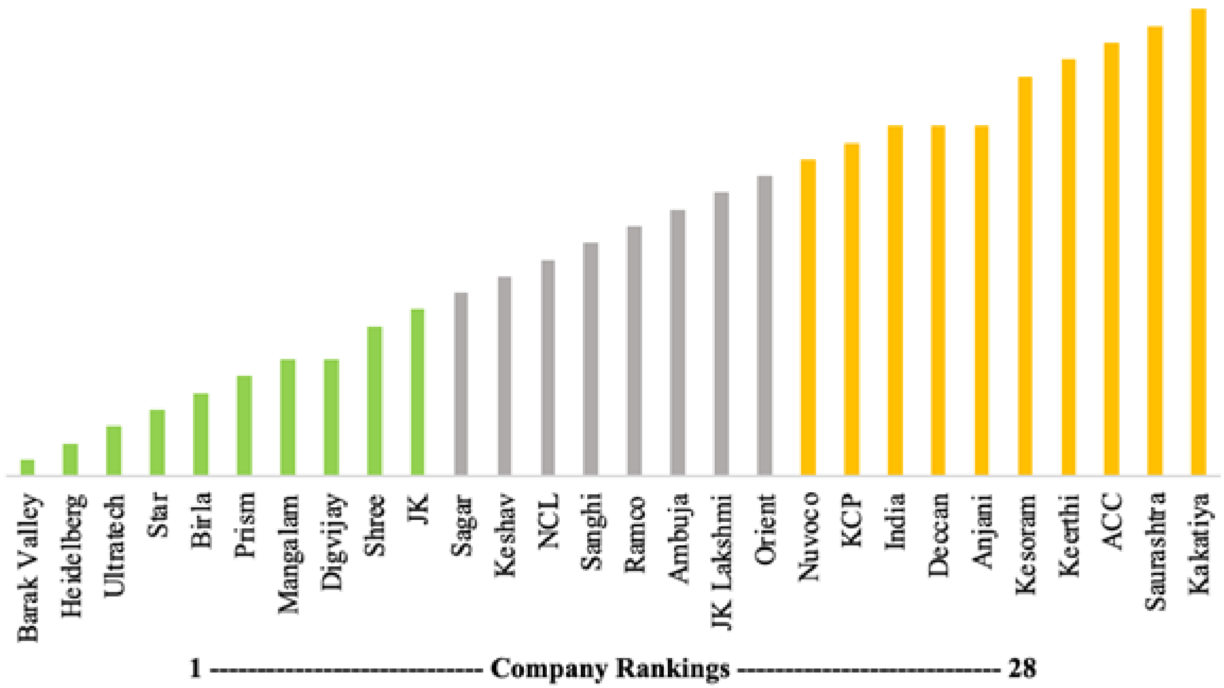

Figure 5. Final Ranking of the Companies

Source: Authors' computations

It is conclusive from the aforementioned table that Barak Valley Cements Ltd. outshone all other cement companies for the year 2022–23, followed by Heidelberg Cement, Ultratech Cement, Star Cement, and Birla Corporation Ltd. In the case of the least-position holders, Kakatiya Cement, Saurashtra Cement Ltd., ACC Ltd., Keerthi Industries, and Kesoram Industries Ltd. are the consistent bottom performers. It is also worth mentioning that 40% of the top 10 cement firms are micro and small-cap companies, whereas 30% of the bottom 10 cement firms are large and mid-cap companies.

5. Discussion

The Indian cement sector is a true behemoth, boasting the title of the world's second-largest producer, trailing only after China. Therefore, this sector is regarded as one of the prominent contributors to India's growth and development, and requires periodic evaluation of its performance and productivity.

The results of this study on VRS-DEA and CRS-DEA indicate that 71% of firms maximise their resource utilisation given their current size due to managerial efficiency, while only 54% of firms operate at a suitable scale, using resources effectively and efficiently, as shown in Table 4. Moreover, all 13 inefficient firms need to focus on the benchmark targets derived from the DEA-CCR (Charnes, Cooper, and Rhodes) model to become efficient decision-making units (DMUs), as highlighted in Tables 5 and 6. Earlier, Sharma (2008) conducted a similar study, examining the technical and scale efficiency of 20 Indian cement entities for the year 2005–06, employing an input-oriented VRS-DEA. Her study found that 50% of firms operated at an optimal size and were technically efficient, a finding consistent with the results of this study.

Kundi and Sharma (2015) evaluated the flexibility and efficiency of 47 cement-producing enterprises of India for the year 2012–13 using the input-oriented DEA and super-efficiency models. They concluded that foreign companies were technically more efficient than their domestic counterparts were, and large-cap entities were more scale-efficient compared to medium and small-sized counterparts due to economies of scale. The findings of this study deviated from them, which suggests that big players are incompetent in capitalising on economies of scale.

Shekhar (2017) employed DEA to assess the relative performance of selected cement entities from 2011 to 2015 and to identify efficient firms based on overall technicality, scale, and pure technicality. His study demonstrated how the company could reduce losses and maximise profits, and highlighted that the profitability of Barak Valley Cement had improved in 2015 compared to 2012. The present study also identified Barak Valley Cement as the top performer.

Chandrasekaran and Chitnis (2019) assigned distinct ranks to 17 cement-producing entities of India for the year 2017–18 using the output-oriented DEA (CRS and VRS) model and the CRS form of super-efficiency. They discovered that prominent entities were unable to reap the benefits of scale economies, and a small-cap firm, OCL India Ltd., stood out as the ace performer among them. The results of the above study align with those of the current study, which suggests that 60% of the efficient firms are small-cap companies, as shown in Table 7. Therefore, in light of this eyebrow-raising scenario and to facilitate a more comprehensive assessment of the cement companies, the current study employed a comprehensive approach. It utilised financial efficiency well-being metrics – Piotroski F-score, Mohanram G-score, Montier C-score, and Beneish M-score, in conjunction with a super-efficiency score – an indicator of operational efficiency – as criteria for implementing MCDM techniques.

Tudu and Das (2024) examined the financial status of 10 selected Indian cement entities for the period from 2014 to 2023, applying the VIKOR method of MCDM and various liquidity, profitability, and efficiency ratios as parameters. They found ACC Cement and Andhra Cement to be the best and worst performers. Similarly, the present study is highly relevant as it employs an innovative approach that combines LOPCOW and ADAM techniques of MCDM with DEA and the Copeland method to evaluate and rank the 28 Indian cement-producing companies for the year 2022-23. This novel approach allows us to identify Barak Valley Cements Ltd., Heidelberg Cement, and Ultratech Cement as the outperformers, as displayed in Table 15.

Furthermore, Ultratech Cement's strategic acquisition of Kesoram Industries' cement business, followed by the acquisition of a stake in Star Cement post 2022–23, highlights the sound operational productivity of both companies, as reflected in our findings of the super-efficiency score mentioned in Table 7. In a similar vein, Ambuja Cements increased its stake in Sanghi Industries in August 2023 and Orient Cement in October 2024, respectively (IBEF report 2025). Additionally, as of June 2025, both industry leaders are presently engaged in advanced negotiations to acquire a stake in Heidelberg Cement, which holds the overall second position in our study.

6. Implications

The present study, unique in its approach, integrates data envelopment analysis (DEA) and multi-criteria decision-making (MCDM) with the Copeland method. This innovative blend for data-driven decision-making, which was unexplored in previous literature, especially in the Indian context, is the cornerstone of our research.

This study can be insightful for company officials, policymakers, investors, and researchers, and can foster more informed decision-making within the Indian cement industry landscape. Company officials with an understanding of the efficiency metrics can serve as a roadmap for strategic investments and transformative operational enhancements. The policymakers can also use the findings to cultivate a competitive environment and refine regulatory frameworks that promote sustainability within the sector. The study also empowers the identification of promising companies and optimises their resource allocation based on the performance rankings presented. Meanwhile, researchers can also build on this study to explore further avenues of efficiency analysis and market dynamics within the cement sector and beyond.

7. Conclusion

Due to the immense contribution of the Indian cement sector to both the domestic and global economy, analysing the performance of cement companies becomes particularly worthwhile. This study not only provides an assessment that helps companies in optimising resource management for value-enhancing activities, but also introduces an integrated and innovative approach for evaluating and appraising companies.

The analysis of the operational efficiency reveals that 71% of cement companies exhibit pure technical efficiency (PTE), i.e. "doing things right", whereas 54% excel in both overall technical efficiency (OTE), i.e., "doing right things at the right scale" and scale efficiency (SE), i.e., "doing things at the right scale" for the year 2022-2023. Interestingly, 60% of the operationally efficient firms are micro and small-cap companies. Around 46%, constituting 13 firms, demonstrate scale inefficiencies and must substantially enhance their resource management to compete with efficient cement companies. Moreover, the super-efficiency DEA model suggests that small players outperform large ones operationally. The application of the LOPCOW-ADAM technique, considering super efficiency score and other proxies of financial health scores as parameters, finds Mangalam Cement as the frontrunner, followed by Barak Valley Cements Ltd. and Ultratech Cement. Furthermore, the comprehensive rank, obtained by integrating various MCDM techniques and the Copeland method, shows that Barak Valley Cements Ltd. outperformed all other cement companies, alongside Heidelberg Cement, Ultratech Cement, Star Cement, and Birla Corporation Ltd. Among the 28 companies, 40% of the top 10 are micro and small-cap companies, showcasing the potential of the smaller players. In contrast, the bottom 10 companies comprise 30% large and mid-cap companies, reflecting the diverse landscape of the cement industry.

Additionally, the strategic manoeuvring of industry leaders to acquire stakes in proficient small-cap companies post-2022–23 is in line with our findings. This alignment with the acquisition trends in the Indian cement industry underscores the practical validity of the proposed approach. Hence, the proposed integrated and innovative approach for data-driven decision-making offers valuable insights for various stakeholders, thereby allowing them to make judicious investment decisions, identify internal strengths & weaknesses, and develop new strategies. Moreover, the outcomes of this study have substantial implications for corporate executives in implementing corrective actions and remedial measures, such as performance gap analysis, resource optimisation, and strategic decisions for M&A and partnership alliances, which will ultimately ensure a long-term competitive edge and sustained growth.

Although insightful, this study has its own constraints. Firstly, it depends on the data from 28 listed companies for the year 2022–23, which may potentially overlook long-term trends. Additionally, the chosen inputs and outputs for the data envelopment analysis (DEA) may not capture all operational efficiency factors. The financial efficiency metrics used may not provide a holistic view of the overall macroeconomic condition. Furthermore, the inherent subjectivity of MCDM techniques may lead to variations in the interpretation. These constraints highlight the necessity for further research to deepen the understanding of efficiency within the sector and beyond.

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Authors' Contribution Statement

Tamladipta Sen: Conceptualisation, Methodology, Data Curation, Formal Analysis, Visualisation, Writing - Original Draft, Review & Editing. Debasis Neogi: Conceptualisation, Methodology, Formal Analysis, Validation, Supervision. Both the authors have read and approved the final version of the manuscript.

Does this article screen for similarity?

Yes

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Data are sourced from companies' annual and other reports, reports published by renowned Asset Management Companies (AMCs), Credit Rating Agencies (CRAs), and reputed stock research websites. All the data is publicly available to its subscribers and may be shared upon request.

Conflict of Interest

The authors have no conflicts of interest to declare. There is also no financial interest to report. The author certifies that the submission is original work and is not under review at any other publication.

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