Critical Analysis of Indian Electric Distribution Utilities Using DEA with Sensitivity Analysis

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***Abstract*—India is presently the world's fifth-largest economy and is also one of the fastest-growing. This rapid growth trajectory positions India on track to become the third-largest economy globally by 2030. Electricity is a critical component of the nation's economic and human development, whose growth is directly or indirectly dependent on the growth of other sectors. Currently. India is the third-largest electricity producer in the world after China and the United States. However, its per capita electricity consumption is relatively low, ranking around 106th globally. This indicates that while India generates a significant amount of electricity, the consumption per person is still modest. The development of the electricity sector in India has occurred in multiple stages, with significant legislative changes implemented in 1991, 1998, 2003 and 2020 in which it aimed to modernize and improve various aspects of the sector, including generation, transmission, and distribution. Though, there have been notable challenges persisting with poor performance, especially in the distribution segment. Owing to this, in the present manuscript, investigations are focused on fifty-five distribution utilities that provide electricity to a significant portion of India's population across twenty-eight states. In this study, evaluation of the relative performance efficiencies and classification of fifty-five Indian Electric Distribution Utilities (IEDUs) is performed. For this, Data Envelopment Analysis is employed to analyze and identify the underlying reasons for the deficiencies in sector performance. The Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC) models have been employed, and overall and pure technical efficiencies have been computed and compared the inefficient with efficient IEDUs for the period of 2016–2019. The outcome specifies performance efficiency scores and classification of IEDUs as decision-making units (DMUs) by sensitivity analysis. The sensitivity analysis reveals that 40 out of 55 DMUs, i.e., 72.72%, come under the category of significantly inefficient and distinctly inefficient with a base technical efficiency score of less than 90%.**

***Index Terms*—Banker-Charnes-Cooper (BCC) model, Charnes-Cooper-Rhodes (CCR) model, data envelopment analysis, decision making units, electric distribution utilities, sensitivity analysis**

I. INTRODUCTION

India, the most populous nation, has one of the world's largest and most complex electricity systems [1]. Furthermore, India's robust economic growth trajectory positions it to become the world's third-largest economy by 2030. As a result of reforms and policy initiatives by the country, generation capacity in the non-renewable and renewable energy sectors has increased from 1,362 MW in 1947 to 4,70,488 MW in February 2025 to support the country's unprecedented economic growth due to globalization, as well as to ensure global climatic protocols, provide access to energy, and achieve energy security [2]. The global climate protocols and agreements have played crucial role in influencing the deployment of clean renewable energy and the growth of grid-connected distributed generation in India. Particularly in the past decade, due to widespread adoption of renewable energies such as solar and wind, the electricity sector has seen dramatic shifts not only in terms of installed capacity but also generation [3–5]. Renewable capacity has increased to 2,13,701 MW, accounting for nearly 46.8% of the total installed capacity in the country. India has achieved a major milestone in its renewable energy sector, surpassing 200 GW of installed capacity. This significant progress aligns with the nation's ambitious goal of attaining 500 GW of renewable energy from non-fossil sources by 2030.

As a result of electricity sector reforms and schemes, India met a peak power demand of 250 GW in financial year (FY) 2024 to 2025, an all-time high. The per capita electricity consumption rose sharply to 1,395 kilowatt-h (kWh) in 2023 to 2024, a 45.8% increase from 957 kWh in 2013 to 2014 [6]. India currently ranks third in the world in terms of electricity production and consumption (after China and the United States) and fifth in terms of installed capacity. At the same time, despite having 18% of the world's population, the country consumes only 6% of its total primary energy consumption in 2017 [7].

The peak energy shortages have been reduced to 0.8% [8]. The year 2018 marked a significant milestone in the Power Sector, with 100% of villages electrified [9]. As a result of electricity legislation, acts, and amendments, the country's power supply requirement has increased rapidly from 8,30,594 million units (MU) to 13,79,000 MU from 2009 to 2010 to 2022 to 2023, shifting from a 10.1% deficit stage to a 0.4% surplus stage. The country has undergone a substantial expansion in its distribution network length from 60,30,148 circuit kilometer (ckm) to 13,279,315 ckm [10]. The increase in per-capita electricity consumption from 559 kWh in 2002 to 2003 to 1,395 kWh in 2023 to 2024 reflects a significant rise in the average electricity usage by individuals in India, however, it falls short when compared to global average consumption. Fig. 1 shows that the global average consumption in developed countries such as Canada, the United States, Australia, Japan, and China, per capita consumption is 15,108 kWh, 12,744 kWh, 9,897 kWh, 7,835 kWh, and 5,119 kWh, respectively [2, 11].

The distribution utilities have become the weakest link in the electricity sector in India because its growth and modernization lagged those of the generation and transmission sectors [12, 13]. In collaboration with its subsidiary, Power grid in collaboration with Grid Controller of India Limited (earlier Power System Operation Corporation Limited (POSOCO) has been involved in synchronizing all regional grids across India. Power grid has demonstrated leadership in advancing smart grid technology in India, as well as eleven high-capacity power transmission corridors.

The electricity distribution sector is often referred to as the "last mile" in the power supply chain and that connects suppliers and consumers. The functioning of the electricity sector and the constitutional framework are crucial first steps in guiding distribution sector reforms in India. Given the concurrent subject status of the electricity sector, overlapping jurisdictions exist for central and state governments [14].

The electricity sector legislation had been introduced in phases beginning with the Electricity Act (EA) 1991, 1998, 2003 and 2020 with the primary goals of incentivizing private electricity production to reduce the gap between demand and supply during Phase-I in 1991, creating the Regulatory Commission for setting the tariff from the Government of India (GoI) during Phase-II in 1998, promoting competition among utilities, mandatory unbundling, and abolishing government control in power sector during Phase-III in 2003 and through an amendment to the Electricity (Rights of Consumers) Rules 2020, the draft electricity Amendment Bill, 2020 will change the current power tariff system. time of day (TOD) Tariff introduction and rationalization of smart metering provisions are the two modifications [10, 15].

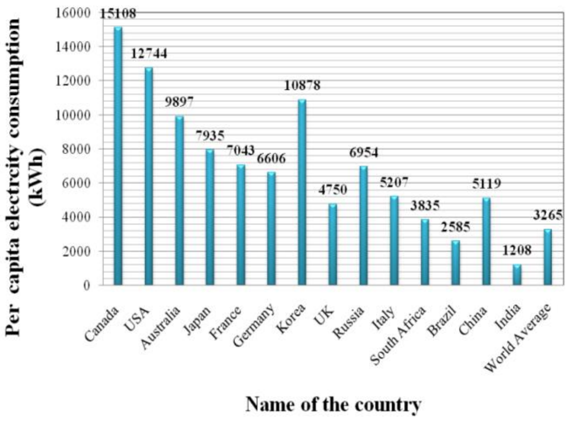

Fig. 1. Per capita electricity consumption of various countries in world 2019.

Fig. 2 depicts the various core initiatives and schemes launched by the GoI after enactment of EA 2003 and the Draft Electricity (Amendment) Bill 2020. The GoI has launched various schemes to achieve different power sector goals. The "Power for All" scheme is aimed at providing 24/7 electricity to all consumers, except agricultural consumers [16–18]. The "Saubhagya," a scheme launched in 2017 to achieve nationwide household electrification, supported this policy even further. Ujwal Discom Assurance Yojana (UDAY), another relevant policy initiative, was launched in 2015 to improve the financial stability of electricity distribution utilities [16]. Electricity Amendment Bill 2020, which lays out a plan for privatizing distribution utilities, and additional initiative is to achieve 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 is the most recent development [19].

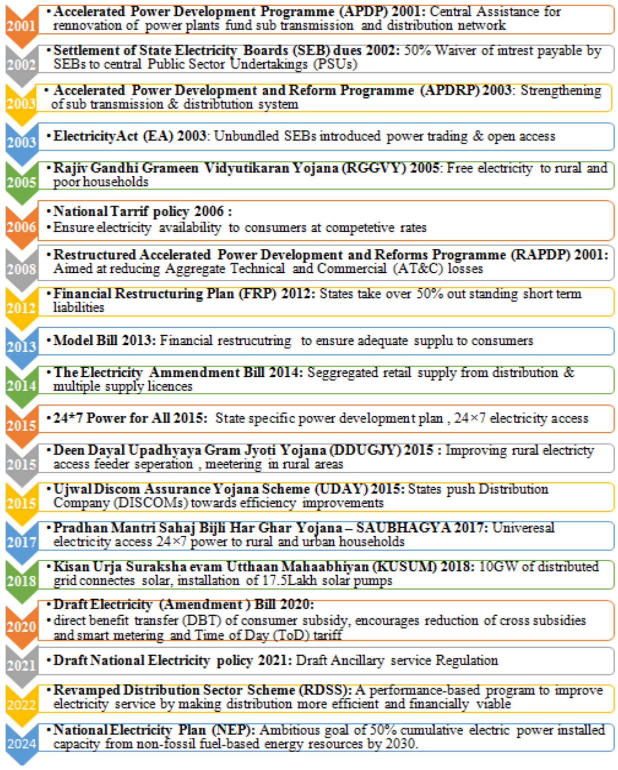

Fig. 2. The various core and/or key initiatives and schemes launched by the GoI after enactment of Electricity Act -2003 and Draft Electricity (Amendment) Bill 2020.

However, it has recently been observed that progress in the distribution system was not satisfactory. Even after the passage of the Electricity Act-2003, electric distribution utilities have been unable to resolve their issues [10, 18]. Because these distribution utilities are frequently referred to as the "cash registers" of the Indian power sector, their commercial viability becomes critical to the sector's overall performance. The distribution sector is in debt, making it difficult to create better infrastructure, provide better services to customers, or pay generators on time due to which the distribution sector is continuously facing significant challenges in the areas of operational and financial performances. As a result, every year, most of the distribution utilities incur losses [10].

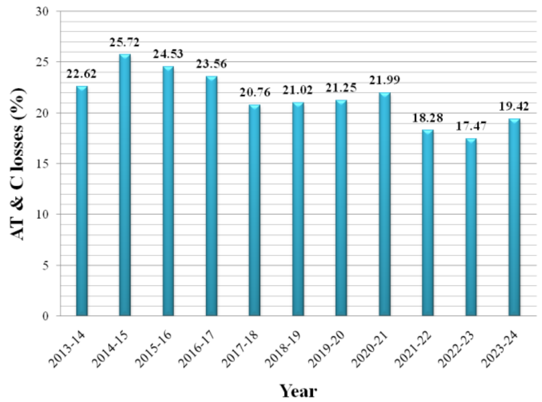

Fig. 3. All India aggregate technical and commercial (AT&C) losses for distribution utilities during the period 2013-2024.

In March 2021, the outstanding amount owed to generation utilities and independent power producers was Rs. 67,917 crores. They are also unable to invest and create the modern infrastructure required to ensure continuous high-quality power or to undergo transition from fossil fuels to renewable energy sources [20]. From 2013 to 2024, India's average aggregate technical and commercial (AT&C) losses for distribution utilities dropped from 22.62% to 19.42%, as shown in Fig. 3 due to several initiatives and legislations in the power sector. However, when compared to the global average (8%), the United States (6%), China (5%), and Japan (4%), losses remain significant. Even within the country, there is a significant variation in performance among the utilities [20, 21].

But the very serious concern is that India consumed only 6% of the world's primary energy in 2017, despite having 18% of the world's population. The very high AT&C losses in the distribution sector, unpaid power bills, delay payment of subsidies, political interference, an old and degraded distribution system, and a failure to maintain electrical equipment for almost three-quarters of the 31 states and union territories experienced extremely high financial losses during the last decade, from 2009 to 2019 [21]. As a result, the current policies are ineffective in ensuring the operational efficiency and financial performance of IEDUs as decision-making units (DMUs), necessitating new policies and regulatory interventions. Such evaluations are critical as GoI intends to take proactive actions to privatize distribution utilities and expedite the franchising process to improve utility operational performance. Despite of the efforts to enhance distribution utility performance, it is also essential to highlight that reforms and restructuring have primarily focused on increasing generation and transmission capacity, completely disregarding the distribution sector both before and after the Electricity Act of 2003's enactment and intern resulted into distribution sector's poor operational and financial state. It is worthwhile to undertake a systematic evaluation of the performance efficiency scores and classification of Indian electricity IEDUs by sensitivity analysis using Data Envelopment Analysis (DEA).

The following are the prime research gaps that are observed from literature.

1) Most of the research has focused on the considerable range in performance of electricity distribution utilities in India during 2006, when the efficiency of 26 integrated electric utilities was analyzed using DEA (Thakur *et al*., 2006) [22].
2) The studies (Yadav *et al*., 2010–2011) evaluated 29 energy distribution circles in Uttarakhand, India, for their effectiveness [23].
3) The studies (Meher and Sahoo, 2016) employed DEA to evaluate the efficiency of the 40 distribution utilities in India spread across 17 states in India for the 2012–2013 period [24].
4) The research employed to analyze the performance of 55 Indian electricity distribution utilities in India for the years 2014–2015 (Bishnoi and Pooja Gaur, 2018) [25].
5) The study (Gopal Sarangi *et al*., 2021) assessed the efficiency of 45 electricity distribution utilities in 21 states in India from 2018 to 2019 [16].

The following are the prime research gaps that are observed in the above literature on performance of 55 unbundled Indian electricity distribution utilities for the latest years after the enactment of multiple electricity distribution reforms on the national grid in India and for five regional grids, as each region has been acting as a separate forum.

Hence, it is very essential to analyze the following.

- The performance variation of unbundled Indian electricity distribution utilities in India.
- To find out the root causes of inefficient utilities using sensitivity analysis.
- To find the gaps in inputs and outputs of inefficient Indian electricity distribution utilities.

Owing to the above discussion, the following are the main objectives of the present research article which needs to be analyzed for performance improvement of the distribution sector.

1) Evaluating the performance of 55 IEDU (DMUs) for 2016–2019 for the specific Charnes-Cooper-Rhodes (CCR) and Banker-Charnes-Cooper (BCC) models of the DEA frontier for the national grid in India.
2) Evaluating the performances of 55 IEDU (DMUs) for 2016–2019 for the specific CCR and BCC models of the DEA frontier for the five regional grids India.
3) Applying an effective mathematical tool called data envelopment analysis (DEA) for assessing the relative efficiency of each decision-making units (DMUs) to assess the performance variation trends of 55 IEDUs (DMUs) for 2016–2019 for the specific CCR and BCC models of the DEA frontier for the five regional grids in India and the national grid in India.
4) Identifying the robustly efficient, marginally efficient, marginally inefficient, significantly inefficient and distinctly inefficient DMUs through sensitivity analysis using CCR Model of the frontier for 55 DMUs in the national grid in India for 2018–2019.
5) Identifying the gaps in inputs and outputs of inefficient DMUs for the specific CCR model of the DEA frontier for 55 DMUs in the national grid in India for 2018–2019.

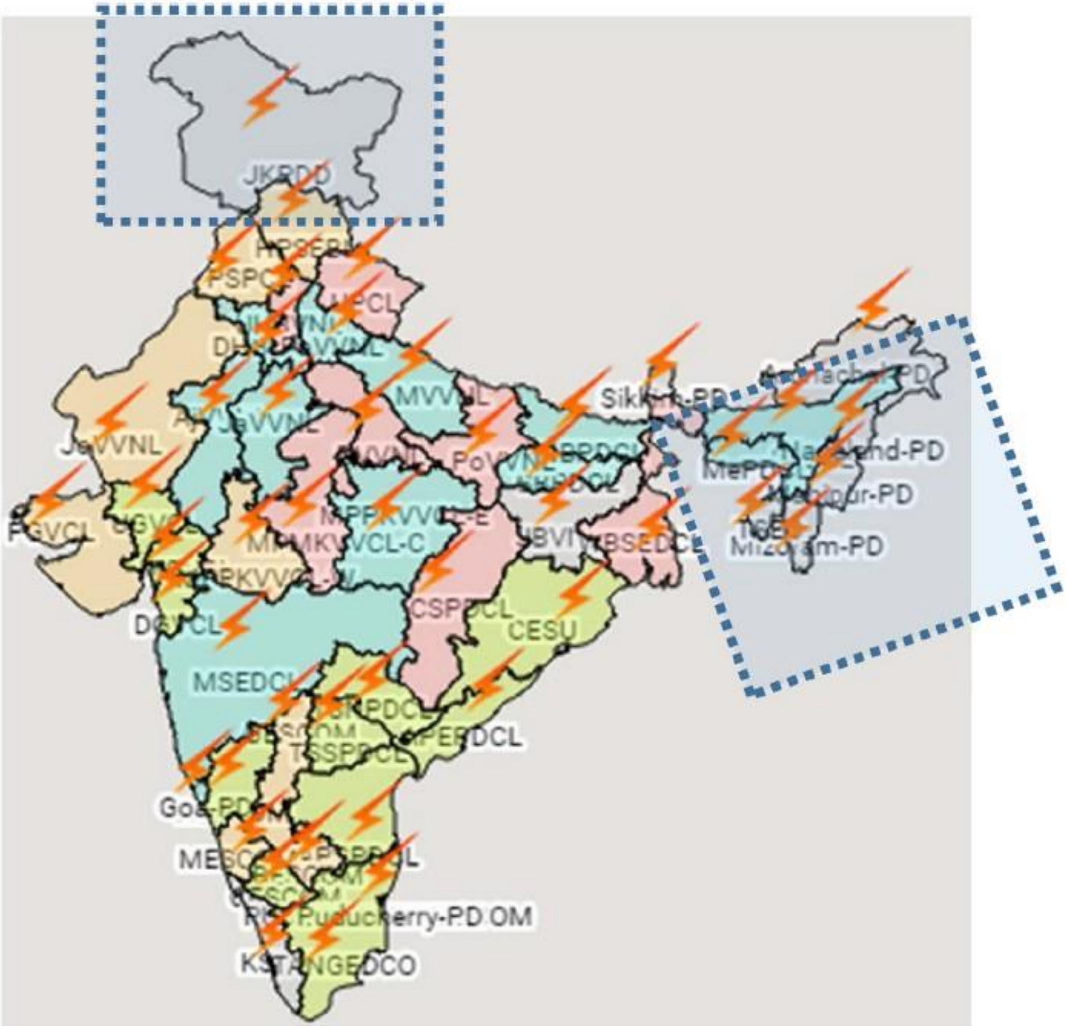

Fig. 4. Indian electricity distribution utilities [26].

This research work introduces a novel DEA-based sensitivity analysis to classify DMU performance at regional and national levels. It categorizes utilities into Robustly Efficient (RE), Marginally Efficient (ME), Marginally Inefficient (MI), significantly inefficient (SI), and Distinctly Inefficient (DI)), offering a more elegant performance assessment than standard CCR/BCC scores.

A total of 55 electric distribution utilities across twenty-eight states and five grids on regional basis, which are Eastern Region (ER) (09), Northeastern Region (NER) (07), Northern Region (NR) (17), Southern Region (SR) (12), and Western Region (WR) (10), were chosen for analysis. Few of the utilities have been shown in Fig. 4.

The rest of the manuscript is as follows: Data envelopment analysis is covered in Section II. Section III discusses the variables and data used in this manuscript. Section IV presents the results and discussions of electrical distribution utilities in India utilizing CCR and BCC and sensitivity analysis using DEA. Section V concludes the manuscript.

II. Data Envelopment Analysis (DEA)

DEA is an effective mathematical tool for assessing the relative efficiency of Decision-Making Units (DMUs) in a variety of domains, including the assessment of electricity distribution utilities. DEA is termed as a non-parametric method by mathematicians and data analysts to assess the performance of multiple DMUs and determine their efficiency levels [27–29].

DEA is commonly employed for benchmarking purposes, where a given set of DMUs is evaluated in terms of their efficiency in utilizing resources to produce outputs. The goal is to identify the most efficient DMUs, which serve as benchmarks for others to improve their performance. Analysis helps decision-makers understand which utilities are performing optimally and which ones could benefit from adjustments or improvements in their operations [30–32].

DEA is particularly useful in situations where traditional econometric models may not be appropriate or when detailed information on the underlying production or cost functions is not available [33]. By using DEA, researchers and policymakers can gain valuable insights into the relative efficiency of different utilities without making assumptions about the functional form of the data-generating process [34–36]. The basic block diagram of research methodology using DEA is shown in Fig. 5. The block diagram presents six inputs: cost of power

(IP1), employee cost (IP2), interest cost (IP3), depreciation (IP4), other costs (IP5), and total expenses (IP6), and two outputs: net energy sold (OP1) and collection efficiency (OP2), which are given to DEA. The arrows pointing from the top to the DMUs represent inputs rupees in crores, and those from the bottom to the DMUs represent outputs in million units (MU) and percentages, respectively. The outcomes of DEA are as follows: CCR efficiency, BCC efficiency, and classification based on sensitivity analysis (RE, ME, MI, SI, and DI).

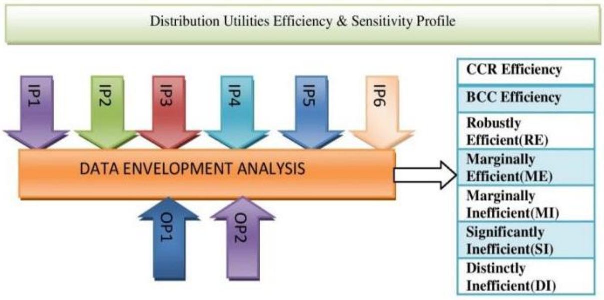

Fig. 5. Block diagram of the research methodology using DEA.

A. CCR Model

The CCR model assumes constant returns to scale (CRS) relationship between inputs and outputs [37]. This means that the efficiency score obtained for each entity assumes that increasing or decreasing the scale of operations will not change the overall efficiency. In other words, the entity is operating at an optimal scale, and any changes in the scale would not affect its relative efficiency. The CCR model calculates two types of efficiencies: technical efficiency and scale efficiency. Technical efficiency measures how well a DMU utilizes its inputs to produce outputs relative to other DMUs in the dataset. It determines the extent to which a DMU is efficiently using its resources. On the other hand, scale efficiency measures whether a DMU is operating at an optimal scale or not. If a DMU is operating efficiently at the optimal scale, its scale efficiency will be equal to one. However, if it is not operating at the optimal scale, its scale efficiency will be less than one.

The CCR model aggregates both technical and scale efficiencies into a single Overall Efficiency (OE) score for each DMU. This overall efficiency score represents the relative performance of a DMU compared to others in the dataset, considering both technical and scale aspects. The primal CCR model formulation is a linear programming problem that maximizes the overall efficiency score of each DMU while satisfying certain constraints related to inputs and outputs. The output oriented CCR model focuses on increasing outputs while keeping inputs fixed, and it determines how much the inputs could be reduced to achieve the highest efficiency [38]. The mathematical expressions for determining technical efficiency and CCR efficiency are given below.

Let the DMU (Decision Making Units) are given by the letter j. Let $x_{i,j}$ and $y_{i,j}$ be the values of the ith input and output on the DMU j. Let the weights assigned by the ith input and output be v_i and u_i, respectively [39].

The fractional programming problem (FPP) is given by the following equation:

$$\max R = \frac{u_1 y_{1k} + u_2 y_{2k} + \cdots}{v_1 x_{1k} + v_2 x_{2k} + \cdots}, k = 1, 2, \times\times\times, n \tag{1}$$

The constraint for the above equation is given by:

$$\frac{u_1 y_{1j} + u_2 y_{2j} + \cdots}{v_1 x_{1j} + v_2 x_{2j} + \cdots} \leq 1, j = 1, 2, \times\times\times, n \tag{2}$$

For every DMU, it is to be taken care that the input must not exceed the output. The major objective of this method is to maximize the DMUs with R being close to one. The above method can be replaced with Linear Programming Problem (LPP) which is given by:

$$\max R(u, v) = u_1 y_{1k} + u_2 y_{2k} + \cdots + u_s y_{sk}$$
$$\text{s.t. } v_1 x_{1j} + v_2 x_{2j} + \cdots + v_m x_{mj} \tag{3}$$

The ration scale is evaluated by using the primal problem where the primal becomes.

$$\max R^* (v^*, u^*) = \frac{\sum_{r=1}^{s} u_r^* y_{rk}}{\sum_{r=1}^{s} v_r^* x_{ij}} \tag{4}$$

The liner programming problem offers the optimal value of R^*, which is less than 1, where efficiency scores are called technical efficiency or CCR efficiency.

B. BCC Model

Unlike the CCR model, which assumes CRS, the BCC model allows for variations in the scale of operations. This means that the efficiency evaluation considers the possibility of increasing or decreasing returns to scale for each DMU. The BCC model introduces an additional constraint known as the total constraint, which is set to one. This constraint affects the multiplier problems used in DEA, introducing an additional variable to account for variations in returns to scale. By adding this constraint, the BCC model can differentiate between DMUs with increasing returns to scale, constant returns to scale, or decreasing returns to scale [40].

The BCC model is also referred to as the variable returns to scale (VRS) model, precisely because it allows for variable returns to scale across the DMUs. This makes it a more flexible and realistic model, as it accounts for the possibility of scale efficiencies varying across different units. The production possible set (P.P.S) of BCC model [41] is defined as

$$P(\text{BCC}) = \left\{ \frac{x, y}{x} \geq x\lambda, y \leq Y\lambda, e\lambda = 1, \lambda \geq 0 \right\} \tag{5}$$

Objective function (BCC_r):

$$\min(\theta_B, \lambda): \theta_B,$$
$$s.t, \theta_B x_0 - X\lambda \geq 0, Y\lambda \geq y_0, e\lambda = 1, \lambda \geq 0 \tag{6}$$

where θ_B is a scalar.

For the BCC model, the optimal solution can be given by $(\theta_B^*, \lambda^*, s^{-*}, s^{+*})$, where θ_B^*, λ^*, s^{-*}, and s^{+*} represents maximal pure technical efficiency, peer weight, input excesses and output short fall respectively.

The entire process is described in a flow chart, which has been mentioned in Fig. 6. The flow chart provides sequential steps for the selection of input and output variables. DEA models identify the efficient and inefficient DMUs, compare the perturb model with base model efficiency, classify the robustness of DMUs and initiatives to be taken to improve their performance [42, 43].

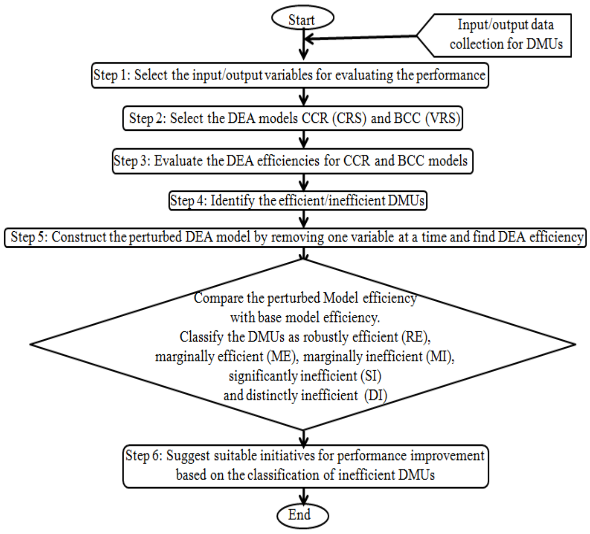

Fig. 6. Performance evolution flow diagram.

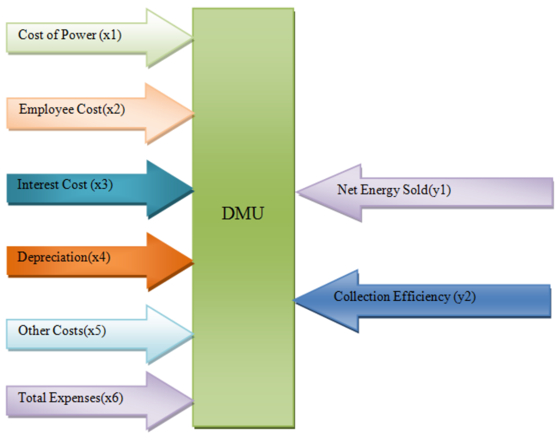

Fig. 7. Inputs and outputs considered in this work.

III. CHOOSING OF VARIABLES AND DATA

In DEA, particularly in electricity distribution, the process of selecting variables and data is crucial for constructing an accurate and meaningful model to evaluate the efficiency of DMUs. To ensure robust analysis, the number of DMUs (entities being evaluated) should be sufficiently larger than the number of selected variables. A rule of thumb suggests that the number of DMUs should be at least three times the number of variables. Regarding Input-Output Selection, variables that directly affect DMUs' performance are typically selected as inputs, while variables representing benefits derived from DMU operations are chosen as outputs [44]. A higher number of inputs and outputs can lead to a larger number of DMUs receiving an efficiency score of 1 (fully efficient), which may complicate the evaluation of other units [45]. Factors such as data availability, relevance to the specific context (electricity distribution), and accuracy of the chosen variables are important considerations in the selection process. The model with six inputs and two outputs explored in this work is depicted in Fig. 7. The arrows pointing from the left towards the DMU represent inputs rupees in crores, and those from the right towards the DMUs represent outputs in million units (MU) and percentages, which correspond to energy sales and collection efficiency, respectively.

DEA's orientation of efficiency assessment is a crucial component. It establishes whether the analysis is input-oriented or output-oriented, with the former emphasizing increasing outputs while maintaining a specific number of inputs. In this current task, 55 decision-making units (DMUs) are evaluated for efficiency using an input-oriented for the 2016 to 2019 period [46, 47].

Data Collection: The data was collected for a diverse range of 55 DMUs operating across 28 states in India [48]. This wide geographical coverage captures the diversity and variations in the electricity distribution sector within the country, including various types of utilities, such as state-owned unbundled distribution, private unbundled, joint ventures, and state-owned bundled utilities [22, 49].

The Power Finance Corporation (PFC) Report 2018 to 2019 is used to collect physical data for various utilities. Table I and Table II provide the statistical data for 2018 to 2019, as well as the correlation between input and output factors. Statistical analysis is a valuable process for investigating relationships between input and output, and it is quantified using metrics such as mean, total, standard deviation, minimum, maximum, and range. According to Table I, the data set has a wide range of input and output variables among the DMUs and is predicted to deliver accurate results. Table II depicts the correlation between input and output variables, which is critical in obtaining accurate results of DEA model [23, 25].

TABLE I: STATISTICS OF ELECTRIC DISTRIBUTION UTILITIES FOR FY 2018–2019

S. No.	Variables	Mean	Sum	Std Deviation	Min.	Max.	Range
1	Cost of Power(x1)	10027.91	551535	10868.26	314.00	63426	63112
2	Employee Cost(x2)	1032.82	56805	1465.85	78.00	8905	8827
3	Interest Cost(x3)	866.00	47630	1393.72	0.10	8248	8247
4	Depreciation(x4)	397.95	21887	532.81	0.10	2945	2944
5	Other Costs(x5)	631.87	34753	1099.65	14.00	7958	7944
6	Total Expenses(x6)	12956.56	712611	14543.6	449.00	83789	83340
7	Net Energy Sold(y1)	16669.09	916800	18599.16	381.00	110178	109797
8	Collection Efficiency(y2)	92.84	5106	7.36	75.71	100	24

TABLE II: CORRELATION BETWEEN INPUT AND OUTPUT VARIABLES FOR THE 2018–2019

Variables	**Cost of Power**	**Employee Cost**	**Interest Cost**	**Depreciation**	**Other Costs**	**Total Expenses**	**Net Energy Sold**	**Collection Efficiency**
Cost of Power(x1)	1							
Employee Cost(x2)	0.7804	1						
Interest Cost(x3)	0.7838	0.8688	1					
Depreciation(x4)	0.9316	0.8565	0.8710	1				
Other Costs(x5)	0.7668	0.4285	0.5389	0.7402	1			
Total Expenses(x6)	0.9932	0.8310	0.8418	0.9586	0.7706	1		
Net Energy Sold (y1)	0.9901	0.8083	0.7973	0.9498	0.7717	0.9910	1	
Collection Efficiency(y2)	0.0261	0.1056	0.0550	0.1579	0.0529	0.0452	0.0777	1

IV. RESULTS AND DISCUSSION

In this section, a comprehensive performance assessment has been conducted for the IEDUs, with consideration of a total of six inputs and two outputs, which are listed in Table I. Two separate scales, the CRS and VRS with input orientation, are used to evaluate performance. For all 55 DMUs that are geographically located in India's five regional grids, the results are shown in Table III.

TABLE III: CCR AND BCC EFFICIENCY ANALYSIS FROM 2016–2017, 2017–2018 AND 2018–2019

DMU number and name	CCR Model- Technical efficiency (TE)				BCC model–Pure Technical efficiency (PTE)			
	2016–2017	2017–2018	2018–2019	CCR Efficiency trend for 2016-2019	2016–2017	2017–2018	2018–2019	BCC Efficiency trend for 2016-2019
Eastern regional (ER) grid electricity distribution utilities (09)								
1_NBPDCL	0.65	0.68	0.72	increasing	0.66	0.68	0.75	increasing
2_SBPDCL	0.61	0.62	0.66	increasing	0.61	1.00	0.82	increasing
3_JBVNL	1.00	1.00	0.82	decreasing	1.00	1.00	0.82	decreasing
4_CESU	0.90	0.85	0.92	decreasing	0.95	0.96	1.00	increasing
5_NESCO	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
6_SOUTHCO	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
7_WESCO	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
8_WBSEDCL	0.69	0.70	0.75	increasing	0.79	1.00	0.91	increasing
9_Sikkim PD	0.96	1.00	1.00	increasing	1.00	1.00	1.00	constant
The average score for the Regional grid	0.87	0.87	0.87	The Regional Grid's overall efficiency (0.87) has not improved in three years.	0.89	0.96	0.92	The Regional Grid's overall efficiency has improved from 0.89 to 92 in three years
The number of DMUs less than the regional grid average CCR score is 03(0.87), 04 (0.87) and 04(0.87) for the assessment periods of 2016-17, 20117-18 and 2018–19 respectively.					The number of DMUs less than the regional grid average BCC score is 03(0.87), 01 (0.96) and 04(0.92) for the assessment periods of 2016-17, 2017-18 and 2018–19 respectively.			
North eastern regional (NER) grid electricity distribution utilities (07)								
10_APDCL	1.00	0.70	0.64	decreasing	1.00	1.00	0.87	decreasing
11_MePDCL	0.68	0.75	1.00	increasing	0.69	0.76	1.00	increasing
12_MSPDCL	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
13_TSECL	0.72	0.57	0.71	decreasing	0.93	0.57	0.71	decreasing
14_Arunachal PD	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
15_Mizoram PD	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
16_Nagaland PD	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
The average score for the Regional grid	0.91	0.86	0.90	The Regional Grid's overall efficiency has deteriorated from 0.91 to 90 in three years	0.94	0.90	0.94	The Regional Grid's overall efficiency (0.94) has not improved in three years.
The number of DMUs less than the regional grid average CCR score is 02(0.91), 03 (0.86) and 02(0.90) for the assessment periods of 2016-17, 2011–7-18 and 2018–19 respectively.					The number of DMUs less than the regional grid average BCC score is 02(0.94), 02 (0.90) and 02(0.94) for the assessment periods of 2016-17, 2017-18 and 2018–19 respectively.			
Northern regional (NR) grid electricity distribution utilities (17)								
17_BRPL	0.73	0.73	0.78	increasing	0.91	0.94	0.84	decreasing
18_BYPL	0.77	0.79	0.80	increasing	0.79	1.00	0.84	increasing
19_TPDDL	0.69	0.72	0.72	increasing	1.00	0.85	0.77	decreasing
20_DHBVNL	0.76	0.87	0.87	increasing	1.00	1.00	1.00	constant
21_UHBVNL	0.59	0.62	0.66	increasing	0.66	0.70	0.83	increasing
22_AVVNL	0.68	0.70	0.70	increasing	0.71	0.72	0.72	increasing
23_JdVVNL	0.73	0.73	0.74	increasing	0.76	0.76	0.75	decreasing
24_JVVNL	0.70	0.73	0.75	increasing	0.73	0.76	0.77	increasing
25_DVVNL	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
26_KESCO	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
27_MVVNL	0.84	0.88	0.78	decreasing	0.84	0.88	0.78	decreasing
28_PaVVNL	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
29_PuVVNL	0.88	0.99	0.97	increasing	0.88	0.99	0.97	increasing
30_UPCL	1.00	0.98	0.96	decreasing	1.00	1.00	0.97	decreasing

31_HPSEBL	0.84	0.75	0.85	increasing	0.92	1.00	1.00	increasing
32_PSPCL	0.99	0.80	0.91	decreasing	1.00	1.00	1.00	constant
33_JKPDD	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
The average score for the Regional grid	0.83	0.84	0.85	The Regional Grid's overall efficiency has improved from 0.83 to 0.85 in three years	0.89	0.91	0.89	The Regional Grid's overall efficiency (0.89 has not improved in three years.
The number of DMUs less than the regional grid average CCR score is 08(0.83), 03 (0.84) and 08(0.85) for the assessment periods of 2016-17, 2011–7-18 and 2018–19 respectively.					The number of DMUs less than the regional grid average BCC score is 03(0.89), 06 (0.91) and 08(0.89) for the assessment periods of 2016-17, 2017-18 and 2018–19 respectively.			
Southern regional (SR) grid electricity distribution utilities(12)								
34_APEPDCL	0.95	0.90	0.67	decreasing	0.97	0.93	0.71	decreasing
35_APSPDCL	0.88	0.79	0.63	decreasing	1.00	0.92	0.81	decreasing
36_BESCOM	0.85	0.84	0.71	decreasing	1.00	1.00	0.82	decreasing
37_CHESCOM	0.81	0.75	0.87	increasing	0.81	1.00	0.88	decreasing
38_GESCOM	0.77	0.73	0.84	increasing	0.79	0.99	0.85	increasing
39_HESCOM	0.78	0.73	0.80	increasing	0.87	0.75	0.83	decreasing
40_MESCOM	0.78	0.78	0.93	increasing	0.78	0.78	0.93	increasing
41_TSNPDCL	0.73	0.73	0.77	increasing	0.75	0.74	0.84	increasing
42_TSSPDCL	0.74	0.78	0.84	increasing	1.00	1.00	1.00	constant
43_KSEBL	1.00	0.94	0.98	decreasing	1.00	1.00	1.00	constant
44_TANGEDCO	1.00	0.94	0.80	decreasing	1.00	1.00	1.00	constant
45_Puducherry	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
The average score for the Regional grid	0.85	0.82	0.82	The Regional Grid's overall efficiency has deteriorated from 0.85 to 0.82 in three years	0.91	0.92	0.88	The Regional Grid's overall efficiency has deteriorated from 0.91 to 0.88 in three years
The number of DMUs less than the regional grid average CCR score is 06(0.85), 07 (0.82) and 04(0.82) for the assessment periods of 2016-17, 2011–7-18 and 2018–19 respectively.					The number of DMUs less than the regional grid average BCC score is 05(0.91), 03 (0.92) and 03(0.88) for the assessment periods of 2016-17, 2017-18 and 2018–19 respectively.			
Western regional (WR) grid electricity distribution utilities (10)								
46_CSPDCL	0.74	0.71	0.77	increasing	0.93	0.84	0.84	decreasing
47_DGVCL	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
48_MGVCL	0.84	0.87	0.90	increasing	1.00	0.88	0.95	decreasing
49_PGVCL	0.91	0.92	0.93	increasing	1.00	1.00	1.00	constant
50_UGVCL	1.00	1.00	1.00	constant	1.00	1.00	1.00	constant
51_MPMaKVVCL	0.70	0.69	0.68	decreasing	0.73	0.72	0.68	increasing
52_MPPaKVVCL	0.78	0.78	0.84	increasing	1.00	0.88	0.91	increasing
53_MPPoKVVCL	0.70	0.68	0.73	increasing	0.72	0.72	0.75	increasing
54_MSEDCL	0.82	0.83	0.83	increasing	1.00	1.00	1.00	constant
55_Goa PD	0.95	1.00	1.00	increasing	1.00	1.00	1.00	constant
The average score for the Regional grid	0.84	0.84	0.86	The Regional Grid's overall efficiency has improved from 0.84 to 0.86 in three years	0.93	0.90	0.91	The Regional Grid's overall efficiency has deteriorated from 0.93 to 0.91 in three years
The average score for the National grid	0.86	0.85	0.86	The National Grid's overall efficiency (0.86) has not improved in three years	0.91	0.92	0.91	The National Grid's overall efficiency (0.91) has not improved in three years
The number of DMUs less than the regional grid average CCR score is 05(0.84), 05 (0.84) and 05(0.86) for the assessment periods of 2016-17, 2011–7-18 and 2018–19 respectively.					The number of DMUs less than the regional grid average BCC score is 02(0.93), 05(0.90) and 03(0.91) for the assessment periods of 2016-17, 2017-18 and 2018–19 respectively.			
The number of DMUs less than the National grid average CCR score is 28(0.86), 28 (0.85) and 28(0.86) for the assessment periods of 2016-17, 2011–7-18 and 2018–19 respectively.					The number of DMUs less than the National grid average BCC score is 18(0.91), 17 (0.92) and 23(0.91) for the assessment periods of 2016-17, 2017-18 and 2018–19 respectively.			

A. CCR/BCC Efficiency Analysis for the 2016 to 2019

The CCR model with the CRS assumption is used to quantify technical efficiency, and the BCC model with the VRS assumption is used to measure pure technical efficiency. The technical efficiency and pure technical efficiency is computed for the assessment years of 2016 to 2017, 2017 to 2018 and 2018 to 2019 using CCR and BCC models and the results are discussed in the following sections. The DMUs DEA efficiency robustness is being computed and classified by sensitivity analysis using the CCR model for the period of 2018 to 2019.

1) Results of CCR model—Technical Efficiency (TE)

The TE score is calculated using the CCR model with constant returns to scale. Table III revealed the following observations. The DMUs display significant variations in technical efficiency scores across all five Regional grids and also across the country for all three assessment years 2016 to 2017, 2017 to 2018 and 2018 to 2019, respectively.

- The DMUs have a national mean score of 0.86, 0.85 and 0.86 for all three assessment years (2016 to 2017, 2017 to 2018, and 2018 to 2019) and have 14.00% inefficiency in India.

- DMU-10 is efficient for the assessment year 2016 to 2017. Similarly, DMU-55 is efficient for the two assessment years i.e., 2017 to 2018 and 2018 to 2019. Further, the DMU-9 is inefficient for the assessment year 2016 to 2017, and DMU-43 is inefficient for assessment year 2017 to 2018 and 2018 to 2019.

The most efficient DMUs (17) are DMU50 (UGVCL-WR), DMU47 (DGVCL-WR), DMU55 (GOA PD-WR), DMU28 (PaVVNL-NR), DMU06 (SOUTHCO-ER), DMU12 (MSPDCL-NER), DMU14 (ARUNACHAL PD-NER), DMU25 (DVVNL-NR), DMU26 (KESCO), DMU45 (PUDUCHERRY PD-SR) and others having with an efficiency score of 1 for assessment year of 2018 to 2019. A few inefficient DMUs are DMU-2 (SBPDCL-ER), DMU10 (APDCL-ER), DMU34 (APEPDCL-SR), DMU35 (APSPDCL-SR), DMU51 (MPMaKVVCL-WR), DMU44 (TANGEDCO-SR) out of 37 inefficient DMUs. It is essential to elaborate on the efficiency scores and individual efficiency indicators of DMU. The findings of the present work are consistent with the results of other investigations [24, 50] regarding the improvement of operational and financial performance of the utilities. It can be observed from Table III the most efficient utilities also performed better on their respective individual efficiency indicators. For instance, DMU50 (UGVCL-WR), DMU47 (DGVCL-WR), DMU55 (GOA PD-WR) also had low AT & C losses, 12%, 5.9%, 15.69%, respectively for the assessment year of 2018 to 2019 (PFC Report 2018 to 2019.) and also, the other cost structure for input variables is the cost of power, employee cost, and interest cost is very low on energy sold for the DMUs. It indicates that the key individual performance indicators have reflections in making DMUs as efficient along with the cost structure of DMUs.

However, there are deviations, such as in the DMU06 (SOUTHCO-ER), DMU25 (DVVNL-NR), and DMU33(JKPD-NR). It should be highlighted that all three performed relatively poorly on key individual indicators such as AT & C losses with 40.08%, 37.12%, and 49.94%, respectively for the assessment year of 2018 to 2019 (PFC Report 2018 to 2019). It emerged as an efficient DMU primarily because of the low cost of power, employee costs, and interest cost per unit of energy sold basis, compared to its peers.

On the contrary, in the case of inefficient DMUs, cost of power, employee cost, and interest cost play very a significant part of their total expenditure of DMUs. For instance, The cost of power (PFC Report 2018 to 2019) DMU35 (APSPDCL-SR), DMU02 (SBPDCL-WR), DMU51 (MPMaKVVCL-WR), is very high as Rs.7.30, Rs.7.47, and Rs.7.00 respectively on per unit energy sold basis for the DMUs. Similarly, the cost of interest of DMU22 (AVVNL-NR), DMU23 (JdVVNL-NR), and DMU24 (JVVNL L-NR) is very high as Rs.1.44, Rs.1.36, and Rs.1.27 respectively on per unit energy sold basis. Similarly, the cost of employee Rs.1.17 and interest Rs.1.08, respectively on per unit sold basis of The DMU44 (TANGEDCO-SR) is very high.

It can be observed from the results that, there is some similarity between the performance of DMUs belonging to the same states, on the contrary, instances where high discrepancies could be observed between the DMUs' performance of a state and its utilities. For instance, all the DMU5, DMU6 and DMUs 7 from Odhisha are efficient except DMU4, where the interest cost is relatively higher compared to the remaining three DMUs in the state.

The national mean efficiency score is 0.86, indicating that DMUs suffer from a relative inefficiency score of 0.14, and there exists scope for further improvement in the efficiency of utilities is 0.14.

2) Results of BCC model—Pure Technical Efficiency (PTE)

The Pure Technical Efficiency (PTE) score is computed using the BCC model assuming VRS. The following points were observed from Table III. The DMUs display significant variations in technical efficiency scores across all five regional grids and across the country for all three assessment years 2016 to 2017, 2017 to 2018, and 2018 to 2019 respectively. The DMUs exhibit Pure Technical Efficiency (PTE) has a national mean score of 0.91 for all three assessment years of 2016 to 2017, 2017 to 2018, and 2018 to 2019 and having with 9.00% inefficiency in India. 32, 33, and 26 DMUs are efficient and the rest 23, 24 and 29 (Out of 55), are inefficient for the three successive assessment years of 2016 to 2017, 2017 to 2018, and 2018 to 2019, respectively.

Table III shows the pure technical efficiency result based on BCC. It is clear that the utilities' pure technical efficiency levels vary significantly. For all utilities, the technical efficiency obtained a mean score of 0.91. It may be observed that 26 DMUs achieved best practices by achieving a pure technical efficiency of 1 and can be considered a benchmark for 29 inefficient DMUs to improve their performance. For example, the technical efficiency score for the inefficient utility DMU-2, i.e., SBPDCL (Bihar), is 82.06%.

The national mean efficiency score was 0.91, indicating that DMUs suffer from a relative inefficiency score of 0.09, and there exists scope for further improving the efficiency of utilities 0.09. National Grid's overall efficiency (0.86 & 0.91) has not improved for all three years in the case of the CCR model and BCC model, respectively.

B. Sensitivity Analysis Using DEA

In some cases, a significantly lower value of an input or a significantly higher value of output may conceal a utility's true efficiency and make it appear efficient. The investigator can use sensitivity analysis to run "What-If" Scenario Analysis (WISA) on the DEA model. The sensitivity analysis is performed in this paper by omitting one input or output variable at a time from the base DEA model and then constructing a new DEA model, i.e., a perturbed model. The current research work employs sensitivity analysis to examine the robustness and performance improvement of the DMUs. The Table IV presents the electricity distribution utilities classification based on sensitivity analysis for 2018 to 2019. The DMUs are being classified into different categories based on their sensitivity. Their details are presented in Table IV. and Fig. 8 shows that out of 55 DMUs in India, there are 4 robustly efficient DMUs, 13 marginally efficient DMUs, no marginally inefficient, 8 significantly inefficient and 30 distinctly inefficient DMUs.

TABLE IV: THE ELECTRICITY DISTRIBUTION UTILITIES CLASSIFICATION BASED ON SENSITIVITY ANALYSIS FOR 2018–2019

Type of Efficiency	Base model efficiency score	Perturbed model Efficiency (when a parameter is removed)	No of DMUs	List of DMUs
Robustly Efficient (RE)	1.0	almost 1.0 and slightly decreases (up to 0.9) when a parameter removed	5	5,12,14,33,45
Marginally Efficient (ME)	1.0	drops significantly (from 0.89 and below) in another situation when a parameter removed	12	6,7,9,11,15,16, 25, 26,28,47,50.55
Marginally Inefficient (MI)	0.9-1.0	0.90-1.00 when a parameter removed	00	Nil.
Significantly Inefficient (SI)	0.90-1.00	drops significantly below 0.90	08	4,29,30,32,40,43,48,49
Distinctly Inefficient (DI)	0.89 and below	Below 0.89 in all other conditions when a parameter removed	30	1,2, 3, 8,10,13,17,18,19,20,21, 22, 23, 24, 27, 31, 34,35, 36,37,38, 39,41,42,44,46,51,52,53,54

TABLE V: THE EFFICIENCY SCORES, CLASSIFICATION AND PERFORMANCE OF DMUS

The efficiency scores of both the base model and perturbed model using Sensitivity analysis for the year of 2018-2019												Classification of DMUs and Performance trend during 2016-2019			
DMU number and name	Base Effi-ciency	Perturbed model efficiency on elimination of the respective variables: Cost of Power (x1)	Employee Cost (x2)	Interest Cost (x3)	Depreci-ation (x4)	Other Costs (x5)	Total Expenses (x6)	Net Energy Sold (y1)	Collection Efficiency (y2)	Classifica-tion of DMUs	Strengths of DMUs (variables)	Classifica-tion of DMUs 2016-17	Classifica-tion of DMUs 2017-18	Classifica-tion of DMUs 2018-19	Performance trend in terms of its efficiency 2016-19
Eastern regional grid electricity distribution utilities (09)															
1_NBPDCL	0.72	0.69	0.54	0.70	0.72	0.72	0.72	0.32	0.65	DI	x1, x2, x3, y1, y2	DI	DI	DI	constant
2_SBPDCL	0.66	0.59	0.58	0.66	0.66	0.66	0.66	0.20	0.66	DI	x1, x2, y1, y2	ME	DI	DI	deteriorated
3_JBVNL	0.82	0.77	0.75	0.82	0.82	0.82	0.82	0.27	0.81	DI	x1, x2, y1, y2	SI	ME	DI	deteriorated
4_CESU	0.92	0.88	0.90	0.92	0.92	0.92	0.92	0.21	0.92	SI	x1, x2, y1,y2	ME	DI	SI	deteriorated
5_NESCO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	RE	y1	ME	ME	RE	improved
6_SOUTHCO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.56	1.00	ME	y1	ME	ME	ME	constant
7_WESCO	1.00	1.00	0.83	1.00	0.82	1.00	1.00	0.61	1.00	ME	x2,x4,y1	DI	ME	ME	improved
8_WBSEDCL	0.75	0.67	0.66	0.75	0.75	0.75	0.75	0.08	0.75	DI	x1,x2,y1	SI	DI	DI	deteriorated
9_Sikkim PD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.48	ME	y2	ME	ME	ME	constant
North eastern regional grid electricity distribution utilities (07)															
10_APDCL	0.64	0.62	0.64	0.64	0.61	0.60	0.64	0.18	0.64	DI	x1,x4,x5,y1	DI	DI	DI	constant
11_MePDCL	1.00	1.00	1.00	1.00	1.00	0.80	1.00	1.00	0.60	ME	x5,y1	RE	DI	ME	deteriorated
12_MSPDCL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	RE	---	DI	ME	RE	improved
13_TSECL	0.71	0.71	0.64	0.71	0.49	0.70	0.71	0.68	0.36	DI	x2,x,4,x5, y1,y2	RE	DI	DI	deteriorated
14_Arunachal PD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	RE	---	ME	RE	RE	improved
15_Mizoram PD	1.00	1.00	1.00	0.92	1.00	1.00	1.00	1.00	0.62	ME	x3,y2	RE	ME	ME	deteriorated
16_Nagaland PD	1.00	0.65	1.00	1.00	1.00	1.00	1.00	0.80	0.67	ME	x1, y1,y2	DI	RE	ME	improved
Northern regional grid electricity distribution utilities (17)															
17_BRPL	0.78	0.66	0.65	0.78	0.78	0.78	0.78	0.17	0.78	DI	x1,x2,y1	DI	DI	DI	constant
18_BYPL	0.80	0.62	0.65	0.80	0.80	0.80	0.80	0.25	0.79	DI	x1,x2,y1	DI	DI	DI	constant
19_TPDDL	0.72	0.65	0.65	0.72	0.72	0.72	0.72	0.18	0.71	DI	x1,x2,y1,y2	DI	DI	DI	constant
20_DHBVNL	0.87	0.86	0.84	0.87	0.77	0.80	0.87	0.08	0.87	DI	x1,x2,x4,x5,y1	DI	DI	DI	constant
21_UHBVNL	0.66	0.61	0.60	0.66	0.66	0.66	0.66	0.09	0.66	DI	x1,x2,y1	DI	DI	DI	constant
22_AVVNL	0.70	0.57	0.60	0.70	0.70	0.70	0.70	0.06	0.70	DI	x1,x2,y1	DI	DI	DI	constant
23_JdVVNL	0.74	0.61	0.70	0.74	0.74	0.73	0.74	0.07	0.74	DI	x1,x2,y1	DI	DI	DI	constant
24_JVVNL	0.75	0.61	0.63	0.75	0.75	0.75	0.75	0.06	0.75	DI	x1,x2,y1	ME	DI	DI	constant
25_DVVNL	1.00	1.00	0.66	1.00	1.00	1.00	1.00	0.40	1.00	ME	x2,y1	ME	ME	ME	constant
26_KESCO	1.00	1.00	0.60	1.00	1.00	1.00	1.00	1.00	1.00	ME	x2	DI	ME	ME	improved
27_MVVNL	0.78	0.76	0.62	0.78	0.72	0.78	0.78	0.14	0.78	DI	x1,x2,x4,y1	ME	DI	DI	deteriorated
28_PaVVNL	1.00	1.00	0.78	1.00	1.00	1.00	1.00	0.20	1.00	ME	x2,y1	DI	ME	ME	improved
29_PuVVNL	0.97	0.94	0.70	0.97	0.97	0.97	0.97	0.22	0.97	SI	x1,x2,y1	ME	SI	SI	deteriorated
30_UPCL	0.96	0.91	0.90	0.96	0.96	0.96	0.96	0.25	0.96	SI	x1,x2,y1	DI	SI	SI	improved
31_HPSEBL	0.85	0.67	0.85	0.85	0.85	0.67	0.85	0.10	0.85	DI	x1,x5,y1	DI	DI	DI	constant
32_PSPCL	0.91	0.79	0.91	0.91	0.91	0.83	0.91	0.02	0.91	SI	x1,x5,y1	ME	DI	SI	improved
33_JKPDD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	RE	------	SI	RE	RE	improved
Southern regional grid electricity distribution utilities (12)															
34_APEPDCL	0.67	0.66	0.66	0.67	0.67	0.67	0.67	0.06	0.67	DI	x1,x2,x5,y1	DI	SI	DI	deteriorated
35_APSPDCL	0.63	0.61	0.63	0.63	0.63	0.61	0.63	0.02	0.63	DI	x1,x5,y1	DI	DI	DI	constant
36_BESCOM	0.71	0.69	0.70	0.71	0.71	0.71	0.71	0.06	0.71	DI	x1,x2,y1	DI	DI	DI	constant
37_CHESCOM	0.87	0.82	0.82	0.87	0.87	0.86	0.87	0.15	0.87	DI	x1,x2,x5,y1	DI	DI	DI	constant
38_GESCOM	0.84	0.79	0.79	0.84	0.84	0.84	0.84	0.14	0.84	DI	x1,x2,x5,y1	DI	DI	DI	constant
39_HESCOM	0.80	0.76	0.78	0.80	0.80	0.79	0.80	0.10	0.80	DI	x1,x2,x5,y1	DI	DI	DI	constant
40_MESCOM	0.93	0.87	0.87	0.93	0.93	0.93	0.93	0.20	0.93	SI	x1,x2,y1	DI	DI	SI	improved
41_TSNPDCL	0.77	0.71	0.77	0.77	0.77	0.69	0.77	0.07	0.77	DI	x1,x5,y1	DI	DI	DI	constant
42_TSSPDCL	0.84	0.84	0.84	0.84	0.84	0.76	0.84	0.05	0.84	DI	x2,x5,y1	ME	DI	DI	deteriorated
43_KSEBL	0.98	0.82	0.98	0.98	0.98	0.96	0.98	0.04	0.98	SI	x1,x5,y1	ME	SI	SI	deteriorated
44_TANGEDCO	0.80	0.65	0.80	0.80	0.80	0.70	0.80	0.02	0.80	DI	x1,x5,y1	ME	SI	DI	deteriorated
45_Puducherry	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	RE	---	DI	ME	RE	improved
Western regional grid electricity distribution utilities (10)															
46_CSPDCL	0.77	0.75	0.76	0.77	0.76	0.75	0.77	0.05	0.77	DI	x1,x2,x4,x5,y1	ME	DI	DI	deteriorated
47_DGVCL	1.00	1.00	0.93	1.00	1.00	1.00	1.00	0.24	1.00	ME	x2,y1	DI	ME	ME	improved
48_MGVCL	0.90	0.88	0.90	0.90	0.90	0.89	0.90	0.20	0.90	SI	x1,x3,x5,y1	SI	DI	SI	constant
49_PGVCL	0.93	0.92	0.91	0.93	0.93	0.93	0.93	0.13	0.93	SI	x1,x2,y1	ME	SI	SI	deteriorated
50_UGVCL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.18	1.00	ME	y1	DI	ME	ME	improved
51_MPMaKVVCL	0.68	0.55	0.55	0.68	0.68	0.68	0.68	0.09	0.68	DI	x1,x2,y1	DI	DI	DI	constant
52_MPPaKVVCL	0.84	0.77	0.77	0.84	0.84	0.84	0.84	0.06	0.84	DI	x1,x2,y1	DI	DI	DI	constant
53_MPPoKVVCL	0.73	0.62	0.62	0.73	0.73	0.73	0.73	0.08	0.73	DI	x1,x2,y1	DI	DI	DI	constant
54_MSEDCL	0.83	0.72	0.71	0.83	0.83	0.83	0.83	0.02	0.83	DI	x1,x2,y1	SI	DI	DI	deteriorated
55_Goa PD	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.24	1.00	ME	y1	DI	ME	ME	improved

The detailed efficiency scores of both the base model, perturbed model and their classification, performance trend using sensitivity analysis for the year of 2018-2019 are presented in Table V.

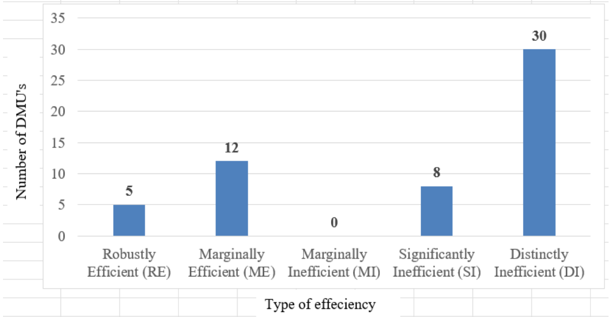

Fig. 8. Classification and its number of DMUs based on sensitivity analysis for 2018 to 2019.

1) Robustly Efficient (RE)

Fig. 9 and Table V exhibit the sensitivity profile of a typical robustly efficient DMU. Among the 55 DMUs, five DMUs have been identified as robustly efficient DMUs. The robustly efficient DMUs are NESCO (DMU5), MSPDCL (DMU12), Arunachal PD (DMU14), JKPD (DMU33), and Pondicherry PD (DMU45) have a DEA efficiency of 1.00 in the base model and remain at 1.00 when all the eight input and output variables are omitted one at a time. For instance, Pondicherry PD (DMU45) also had a relatively low-cost structure (PFC_2020) for input variables of cost of power, employee cost, and interest on energy sold basis and an individual efficiency score of low AT&C losses (17.47%), and also the performance level improved from distinctly inefficient” to “robustly efficient” from 2016 to 2019.

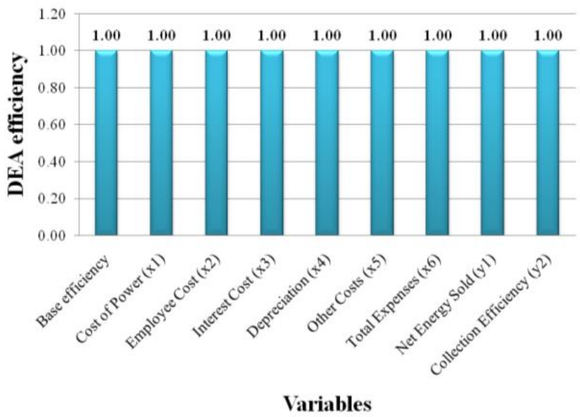

Fig. 9. Sensitivity profile of robustly efficient DMUs MSPDCL (DMU12).

2) Marginally Efficient (ME)

Fig. 10 and Table V exhibit the sensitivity profile of a typical marginally efficient DMU. Among the 55 DMUs, twelve have been identified to be marginally efficient, they are DMU6, DMU7, DMU9, DMU11, DMU15, DMU16, DMU25, DMU26, DMU28, DMU47, DMU50, and DMU55. Case 01: The technical efficiency DMU25_DVVNL during FY 2018 to 2019 stayed at 1.00 for the base model and dropped to 0.65 and 0.39 for the employee cost and net energy sold (PFC Report 2020) in the perturbed model. The critical factors and strengths for this DMU_25 is net energy sold and employee costs. It is further observed that from the above set of marginally inefficient DMUs, the most common strength of all these is net energy sold, and employee cost in a few cases.

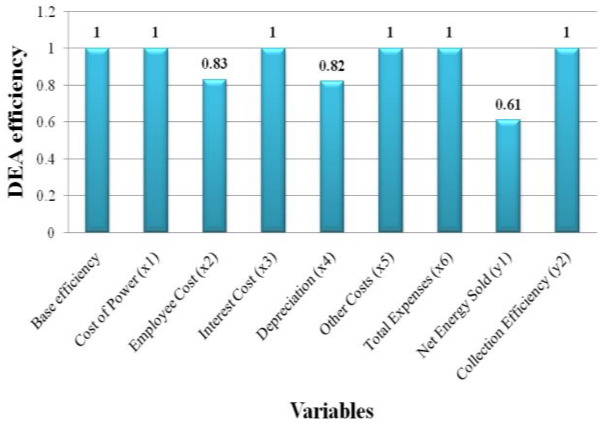

Fig. 10. Sensitivity profile of DMU25_DVVNL marginally efficient (13 DMUs).

3) Significantly Inefficient (SI)

Fig. 11 and Table V exhibit the sensitivity profile of a typical significantly inefficient DMU. Among the 55 DMUs, eight have been identified to be significantly efficient, they are DMU4, DMU29, DMU30, DMU32, DMU40, DMU43, DMU48, DMU49.

Case 1: The technical efficiency DMU40_MESCOM during FY 2018 to 2019 stayed at 0.92 for the base model and dropped to 0.8725 (cost of power), 0.39 (employee cost) and 0.20 (net energy sold) in the perturbed model. The critical factors and strengths for this DMU40_MESCOM are the cost of power, employee costs and net energy sold (PFC Report 2020). The individual efficiency score of relatively low AT&C losses (28.74%), and the performance level improved from “distinctly inefficient” to “significantly efficient” from 2016-2019.

Case 2: The technical efficiency DMU4 during FY 2018 to 2019 stayed at 0.92 for the base model and dropped down below 0.90 which are the cost of power (0.88), employee cost (0.90), net energy sold (0.21) in the perturbed model. The critical factors for this DMU 4 are the cost of power, employee cost and net energy sold. These are strengths of DMU 4.

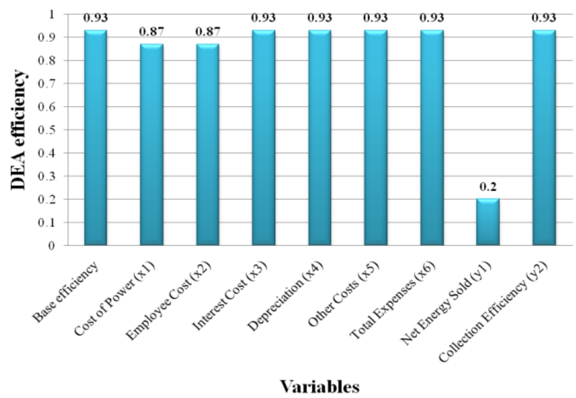

Fig. 11. Sensitivity profile of DMU40_MESCOM significantly

inefficient (SI) (08 DMUs).

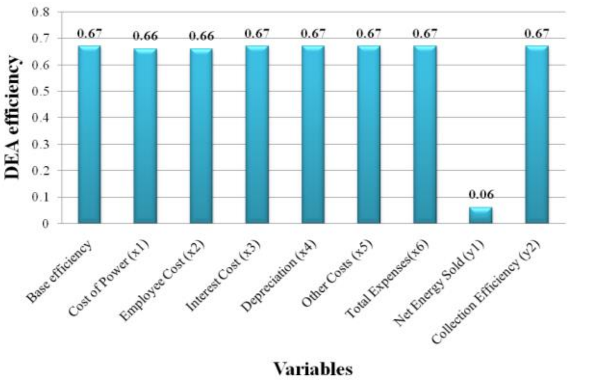

Fig. 12. DMU 34_APEPDCL Sensitivity profile of distinctly inefficient (DI) DMU.

4) Distinctly inefficient (DI)

Fig. 12 and Table V exhibit the sensitivity profile of a typical distinctly inefficient DMU. Among the 55 DMUs, thirty have been identified to be distinctly inefficient, the numbers of these DMUs are 1, 2, 3, 8, 10, 13, 17, 18, 19, 20, 21, 22, 23, 24, 27, 31, 34, 35, 36, 37, 38, 39, 41, 42, 44, 46, 51, 52, 53, 54.

The technical efficiency DMU34_APEPDCL during FY 2018 to 2019 stayed at 0.67 for the base model and dropped to 0.66 (cost of power), 0.66 (employee cost) and 0.06 (net energy sold) in the perturbed model. The critical factors and strengths for this DMU34_APEPDCL are the cost of power, employee cost and net energy sold (PFC Report 2020). Even though the individual efficiency score of low AT&C losses (18.47%), there is no change in performance level improvement during 2016 to 2020 due to high cost Rs. 6.90 of power and employee cost Rs. 0.69, respectively on per unit energy sold basis.

5) A gap assessment

A gap assessment can be generated for each inefficient utility, and it is very useful in providing targets for performance enhancement to inefficient utilities.

The results of the sensitivity analysis demonstrate that the absence of several variables causes significant variation in efficiency scores. The outcome is shown in Table V, which displays the efficiency scores for both the base model and the perturbed model. Specifically, the effects of removing input and output variables are explored below. Table V, the base model, perturbed model efficiency scores, and sensitivity analysis have been employed to classify DMUs and track their performance from 2016 to 2019.

Table V summarizes the differences in the relative efficiencies of the DMUs obtained by removing input and output variables from the DEA model one at a time. The values enclosed in the Table represent the differences in efficiency between the original and the result of changing input and output factors. Sensitivity analysis reveals that significant variation in efficiency scores occurs when different inputs and outputs are eliminated.

For example, though DMU50_UGVCL has an overall efficiency score of 1, it becomes 0.18 excluding the net energy sold factor, while the efficiency scores remain 1 in all other cases. Thus, energy sold is the strength of this DMU50_UGVCL and hence DMU50_UGVCL is categorized as a marginally efficient utility. The MSPDCL (DMU12), Arunachal PD (DMU14), and DMU 33_JKPDD are identified as robustly efficient, and their efficiency remains at 1 for all conditions.

The DMU34_APEPDCL has an overall efficiency score of 0.67, which is distinctly inefficient. On eliminating the cost of power, employee costs, and net energy sold, a significant decrease in efficiency is observed and the gas assessment report is presented in Table VI. This implies that these three factors are advantageous for DMU34_ APEPDCL and can play a significant role in efficiency improvement. The most DMUs (30) are distinctly inefficient, but they require more attention and better insights to improve their efficiency. As a result, sensitivity analysis identifies the input and output factors that benefit the corresponding DMUs and suggests resource allocation strategies to maintain their competitive advantage.

TABLE VI: GAS ASSESSMENT REPORT

Name of the DMU	**34_APEPDCL**
Year of Assessment	2018–19
Classification	Distinctly Inefficient
DEA Efficiency	0.67 to 0.06
Major Gaps	Cost of power, employee costs and net energy sold

V. CONCLUSION

The Indian electricity distribution sector is undergoing a transition process to address various challenges and improve its efficiency. The distribution sector plays a crucial role in the overall electricity supply chain, as it is responsible for delivering electricity from the power generation plants to the end consumers. The electricity distribution system is commonly considered the weakest link in the entire electricity supply chain. In this context, this research work is being undertaken to evaluate and determine the relative performance of 55 IEDU (DMUs) for 2018 to 2019 for the specific CCR and BCC models of the DEA frontier. From analysis, it is found that only 17 DMUs were found efficient under the CCR model, while 26 were efficient under the BCC model for 2018 to 2019. The remaining 38 (29) DMUs are inefficient because of the inappropriate scale of operation and lack of pure technical efficiency with CCR (BCC). The DMU50 (UGVCL-WR), DMU47 (D GVCL-WR), and DMU55 (GOA PD-WR) had low-cost structures for input variables as the cost of power, employee cost, and interest cost, energy sold, low AT & C losses. It reveals that the key individual performance indicator has an impact in making DMUs as efficient along with the cost structure of DMUs. From sensitivity analysis it is found that there is a significant variation in efficiency scores, out of 55 DMUs in India, there are 5 Robustly Efficient DMUs, 12 marginally efficient DMUs, no marginally inefficient, 8 significantly inefficient and 30 distinctly inefficient DMUs. The marginally efficient DMU25_DVVNL is ahead of marginally inefficient DMUs which are sensitive to changes in data and could become inefficient very quickly with the change in a few variables. The multi-year analysis for 2016 to 2019 for DMU35_APSPDCL indicates that trend of performance which is distinctly inefficient for three years. These DMUs need greater focus on the performance of all the variables.

Thus, it needs immediate attention to prevent them from becoming inefficient by taking certain specific long-term initiatives such as:

1) By signing power purchase agreements (PPAs) with renewable energy generators, DMUs can secure cost-effective and eco-friendly power.
2) Entering long-term PPAs with power producers can provide stability and predictability in power costs as these long-term contracts can shield DMUs from short-term price fluctuations and volatile energy markets.
3) Improving the efficiency of the distribution network through measures like feeder segregation, upgrading distribution infrastructure, and reducing AT&C losses.
4) Adopting smart distribution with advanced technologies in distribution sector, such as smart meters, distribution automation, and grid management systems, can enhance operational efficiency and reduce costs associated with manual meter reading, outage management, and maintenance.
5) Engaging in competitive bidding and exploring power exchange options can lead to better deals and more competitive power procurement prices.
6) Implementing TOD tariffs can incentivize consumers to shift their electricity consumption to off-peak hours when the demand is lower to improve the overall performance.

The findings will assist the DMUs and policy makers in developing a better understanding of the vulnerabilities and strengths in making rational decisions to improve the distribution sector's performance. Further it is suggested from the results that to identify the key factors contributing to financial stress among DMUs in the southern regional grid of India, as many of these utilities are underperforming compared to those in other regional grids.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Both authors contributed equally to all stages of the preparation of manuscript.

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