Performance Assessment of Indian Electric Distribution Utilities Using Data Envelopment Analysis (DEA)

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***Abstract*—One of the most important links in the electricity market is the electricity distribution sector as it involves interfacing the end customers and providing the revenue that is required for running the entire chain of the electricity sector. Besides, it provides power to the individual consumers at relatively lower voltages by absorbing high voltage power from the transmission sector and involves revenue collection from the consumer sector. The primary aim of the distribution sector, as stated by the Provisions of Tariff policy, Government of India, 2016, is to provide reliable, quality and sustainable power at reasonable rates. Despite the restructuring of Indian Power Sector post implementation of Electricity Act 2003, the electricity distribution utilities, in the recent past, are experiencing poor financial results irrespective of their ownership (public, private or joint sector). This has been attributed to various factors related to economic, environmental, physical, social and technical streams related to the operation of the utilities. The performance of these electricity distribution utilities can be assessed using Data Envelopment Analysis (DEA) tool which is extensively used in the recent past by the researchers to analyze the performance of entities of other sectors. The successful employment of DEA for evaluating the electricity distribution utilities lies with the proper selection of input and output variables that are chosen for the analysis. The current work analyzes the relative comparative performance of electricity distribution utilities across India and identifies inefficient utilities besides providing peers/reference, slack analysis for effective strategic improvement.**

***Index Terms*—Electric distribution utilities, data envelopment analysis, decision making unit, relative efficiency measurement, CCR model, BCC model, efficiency scores and slack analysis**

I. INTRODUCTION

The electric power development of any nation is measured in terms of its per capita consumption of electricity [1]. The per capita consumption of electricity is a function of electricity generated, transmitted, and distributed in the country. The provision of electrical energy has become synonymous with economic development and social progress today [2]. Electricity is regarded not only as a basic need, but also as a service that should be available to all with quality, continuity, sustainable and at an reasonable price [3], [4]. Electricity is one of the key drivers for rapid economic growth and poverty reduction for developed and developing countries. The electricity consumption is considered as indicator of the socio economic progress and development of technologies [5].

Since the independence in 1947, India has enormously increased its installed capacity of generation and developed its transmission and distribution sector. The total generating capacity has enhanced from 1362MW in 1947 to 379500MW by the end of February 2021. With rapid progress in industrialization resulting in better standard of living of the people, the per capita consumption of electricity has risen from 16.3kWh in 1947 to 1208kWh in 2019-2020 [4], [6]. The total consumption of electricity across the country has increased from 433TWh to 1598TWh in the period 2003-2019. Despite being the world's third-largest energy consumer, the per capita electricity consumption in India is quite low in comparison to the developed countries [7]. The per capita consumption in developed countries of Canada, USA, Australia, Japan and China is 15141kWh, 12701kWh, 9892kWh, 7865kWh and 4475kWh, respectively. Even though there is a huge growth in electricity generation, the demand has also been reaching a new peak which has resulted in acute power shortages (in different states) across the country. Government of India has laid special emphasis on enhancing the generation capacity besides taking various measures to reduce the losses in the transmission and distribution sector and implementing demand side management for effective utilization of the limited resources. The number of villages electrified in India has also increased from 3061 in 1950 to 597416 in 2021. The Government of India (GoI) has invested nearly Rs.756 billion for providing electricity to the villages under the scheme Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) [8]. Apart from this, the scheme of "Integrated Power Development Scheme" (IPDS) was launched with clear

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objectives of improving of sub-transmission and distribution network besides metering of distribution transformers/feeders/consumers in the urban areas.

Among the generation, transmission and distribution businesses of the electricity sector value chain, the weakest link is the distribution sector [9]. The generation utilities found difficulties in receiving their dues from their biggest buyers; mainly electricity distribution utilities, which suffer huge financial losses due to various problems, associated with the performance like operational inefficiency and high loss level aspects [10]. It is observed that the first phase power sector reforms introduced in 1991, were not successful in improving the technical efficiency, financial performance of electricity utilities. Some states like Odisha & Delhi privatized the Electricity distribution activity to enhance the performance of the Electricity distribution utilities [11].

The key challenge experienced by developing nations is to operate and regulate their Electricity Distribution utilities in an efficient and economical way where there is monopoly in the distribution sector, which is the natural monopoly activity of distribution within the geographical area [12], [13]. The Government of India (GoI) is providing incentives for technically and commercially viable distribution utilities besides implementation of organizational reforms and latest regulatory reforms. To strengthen the distribution utilities across the country, GoI has set up a National Electricity Fund (NEF). This provides subsidies on the interests on loans claimed by the distribution utilities of both public and private sector. In the literature, most of the research is focused on wide variation of performance of electricity distribution utilities in India [14]. It is essential to analyze the performance variation and identify inefficient utilities besides providing the peers for the improvement in system performance.

The evaluation of electric distribution utilities using Data Envelopment Analysis (DEA) has resulted in poor efficiency scores of the DMUs with considerable units operating inefficiently [15]. The Malmquist index-based performance evaluation have shown positive productivity growths for distribution utilities in India despite being inefficient [16]. In the literature, most of the research is focused on wide variation of performance of electricity distribution utilities in India. It is essential to analyze the performance variation and identify inefficient utilities besides providing the peers for their improvement for the latest years as we are looking ahead for Electricity Act 2021. India, being a large country, has been divided into five regional grids. The performance of the utilities in each regional grids differs from those of the utilities in the neighboring regional grids due to peculiar characteristics of the regional grids. The determination of the relative performance of these distribution utilities across the country and region-wise is a potential challenge. This can be addressed effectively by employing DEA for the entire distribution utilities across the country. The CCR and BCC models of DEA can be employed and compared for further analysis of the inefficient DMUs.

A total of 55 electric distribution utilities spread in 28 states and five regional electricity grids, Eastern (09), North Eastern (07), Northern (17), Southern (12) and Western (10) have been chosen across India for analyzing their performance. The selected electricity distribution utilities can be noticed in Fig. 1. The performance of these utilities has been estimated using data envelopment analysis, which is a powerful tool employed in the recent past by many researchers across the globe [2], [7].

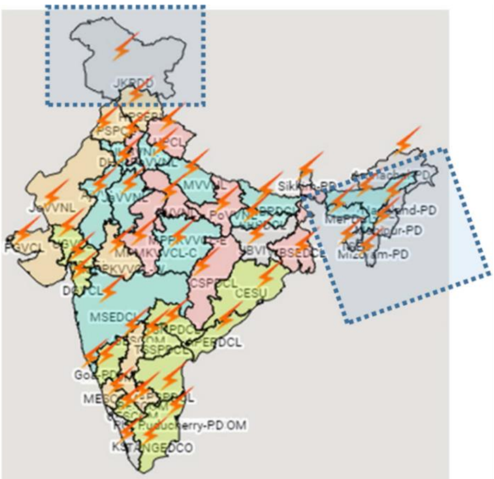

Fig. 1. Electricity distribution utilities across India. Source [11].

The remaining of the paper is as follows: Section II deals with Data Envelopment Analysis. The variables and data used in this work are given in Section III. The subsequent Section IV gives the results of performance assessment of electricity distribution utilities in India using Charnes, Cooper and Rhodes (CCR) and Banker, Charnes and Cooper (BCC) models for DEA's and the manuscript is concluded in Section V. The references are included in Section VI.

II. Data Envelopment Analysis

Data Envelopment Analysis, often referred as DEA, is a powerful tool to measure relative efficiency of electricity distribution utilities often referred as decision-making units (DMUs). Data Envelopment Analysis, often referred as DEA, is a commonly employed method in determining economics of multiple utilities. It is a nonparametric method widely used by mathematicians and data analysts for examining the performance of multiple utilities. It is primarily employed for benchmarking of given set of utilities [10], [11]. The basic block diagram of research methodology is shown in Fig. 2.

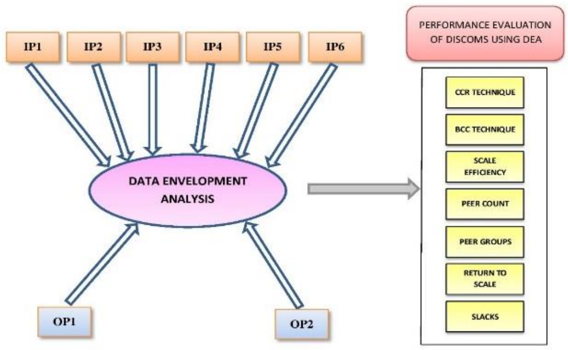

Fig. 2. Block diagram of the research Methodology using DEA.

The advantages of the DEA include [14]:

- DEA offers efficiency using numerical data. It does not employ the subjective opinions of the stakeholders for determining efficiency. Hence it can be termed as being objective method offering accurate results.
- DEA does not require any mathematical expressions or any equation for production function which relates the inputs and outputs. It is non-parametric in nature.
- DEA can identify any excess input data or shortage of outputs as it offers a result of inefficiency.
- Numerous inputs and outputs can be handled by DEA simultaneously.
- Excessive number of inputs than required or the shortage of number of outputs leads to inefficiency in DEA programming.
- Inputs and outputs of different types of measurement can be easily employed in DEA. For example, number of transmission lines and revenue generated can be employed as inputs.
- For effective calculation of efficiency, dummy variables can be used.
- Nature of Returns to Scale (RTS) can be identified at each part of efficient frontier.

Despite the numerous advantages mentioned above, DEA still has certain challenges to overcome:

- The convergence of DEA solutions during computation of absolute efficiency is quite slow.
- The efficiency calculations are influenced by small number of inputs and larger number of outputs
- The results are sensitive to the selection of input and output variables.
- The larger the number of decision-making units (DMUs) delivers better results. A limited number of DMUs may result in erroneous results.
- Statistical noise is not considered as DEA is a deterministic method.

The basic efficiency of any Decision Making Unit (DMU) used in DEA is defined as weighted sum of all the outputs considered to the weighted sum of inputs [15]. Two types of models are employed in the current work namely, CCR model and BCC model [16].

A. CCR Model

This model is named after Charnes, Cooper and Rhodes (CCR) who introduced this [17]. In this model, a constant return to scale relationship is assumed between inputs and outputs. The technical and the scale efficiencies are aggregated into a single overall efficiency (OE) which can be obtained for each entity employed for DEA. The principle of CCR can be explained as follows.

This model calculates the Overall Efficiency (OE) for each unit, where both technical efficiency and scale efficiency are aggregated in to one value. The primal CCR model is explained as follows.

Let the DMU (Decision Making Units) be represented by the letter *j*. Let $x_{i,j}$ and $y_{i,j}$ be the values of the *i*th input and output on the DMU *j*. Let the weights assigned by the *i*th input and output be v_i and u_i, respectively.

The fractional programming problem (FPP) is given by:

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

The above equation is subjected to the following constraint:

$$\frac{u_1 y_{1j} + u_2 y_{2j} \cdots}{v_1 x_{1j} + v_2 x_{2j} \ldots} \le 1,\ j = 1, 2, \cdots n$$

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

$$\text{Maximize } R(u,v) = u_1 y_{1k} + u_2 y_{2k} + \cdots, + u_s y_{s,k}$$
$$\text{Subjected to } v_1 x_{1j} + v_2 x_{2j} + \ldots v_m x_{m,j} = 1$$

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

$$\text{Maximize } R^*\left(v^*, u^*\right) = \frac{\sum_{r=1}^{s} u_r^* y_{r,k}}{\sum_{i=1}^{m} v_i^* x_{i,j}}$$

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

B. BCC Model

This model is developed with slight modifications to CCR model and is named after Banker in addition with Charnes and Cooper [18]. It is employed when an assumption of variable returns to scale is considered among the inputs and outputs. If the total constraint equal to one is adjoined, they are known as BCC models. This added constraint introduces an additional variable into the multiplier problems. This extra variable makes it possible to affect returns-to scale evaluation. This return to scale is increasing or constant or decreasing. So the BBC model is also referred to as the Variable Returns to Scale (VRS) model.

The Production Possible Set (P.P.S) of BCC model [18] is defined as

$$P(\text{BCC}) = \left\{ \frac{x, y}{x} \ge X\lambda,\ y \le Y\lambda,\ e\lambda = 1,\ \lambda \ge 0 \right\}$$

Objective function (BCC*r*):

$$\min(\theta_B, \lambda) : \theta_B$$
$$\text{subject to } \theta_B x_0 - X\lambda \ge 0,\ Y\lambda \ge y_0,\ e\lambda = 1,\ \lambda \ge 0$$

where θ_B is a scalar.

An optimal solution for BCC model is presented 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 commonly used terms in the DEA analysis are listed below.

1) Returns to scales (RTS)

If increase in outputs is in the same proportion of the increase in inputs, then the returns to scale is referred as Constant Returns to Scale (CRS). If changes in the outputs are non-proportionate, then it is referred as Variable Returns to Scale (VRS). The VRS can be classified as Increasing Returns to Scale (IRS) and Decreasing Returns to Scale (DRS). These have been represented in Fig. 3 respectively.

The variations in the output are indicated by the slope of the curves. In Fig. 3 (a). It can be noticed that the slope is constant indicating a constant return while in Fig. 3 (b) and Fig. 3 (c) these are increasing and decreasing respectively.

2) Potential Improvement

The advantage of DEA is that it offers a scope for potential improvement for each DMU. It not only gives an efficiency score for every DMU but also provides the details of the areas which the DMU fares well and where the DMU is inefficient. This provides targets which can help the inefficient units to improve their performance.

3) Reference comparison

Another added advantage of DEA is that it provides ample scope for comparison by identifying reference DMUs in the analysis. This helps in setting of targets for the inefficient units.

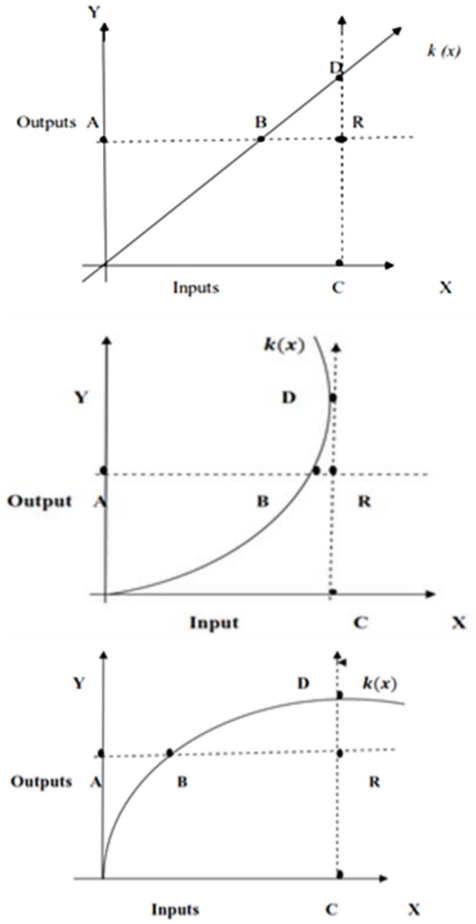

Fig. 3. Returns to scale: (a) Constant returns to scale (CRS), (b) increasing returns to scale (IRS), and (c) decreasing returns to scale (DRS).

4) Peer group

The major comparison between the DEA models of CCR and BCC is that the CCR model provides overall technical efficiency while the BCC model provides pure technical efficiency. This results in a straight-line efficiency for CCR models while the BCC models can have convex line efficiency. Also, the BCC model ignores the scale efficiency which results in lowering of differences in inefficiencies of the DMUs. Besides CCR model works with Constant Returns to Scale while BCC model is developed with Variable Returns to Scale.

DEA identifies a set of efficient DMUs for each of inefficient DMUs, which are collectively referred as a Peer Group. This helps in imitating their performance by the inefficient DMUs to achieve a better efficiency. The entire process has been incorporated in a flow chart which has been mentioned in Fig. 4. The flowchart provides the sequential steps for identifying the inefficient DMUs from data collection, model selection, evaluation of scale efficiency and determining the peer group.

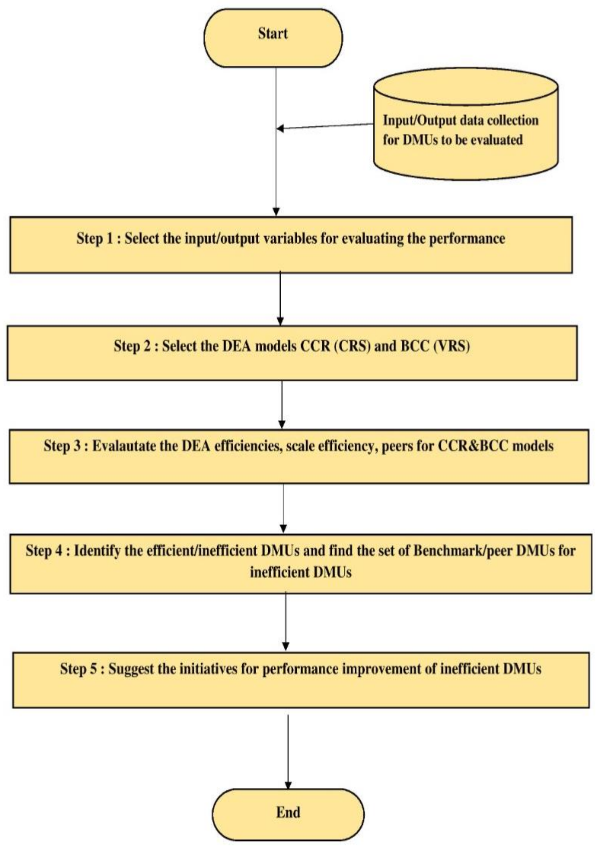

Fig. 4. Performance evolution flow diagram

DEA identifies a set of excellent units for each group of inefficient DMUs. These excellent units are collectively refereed as a Peer Group. This helps in imitating their performance by the inefficient DMUs to achieve a better efficiency.

III. Choosing of Variables and Data

DEA involves large number of input and output variables which must be carefully selected at the start of the study [14], [15]. For accurate model, the number of DMUs should be thrice the number of identified variables [19], this condition is met by selection of input output variables. The variables must be chosen such that they are relevant to the study and they influence the relative performance of the DMUs. Screening, either qualitative or quantitative, is to be employed for picking suitable input and output variables and irrelevant variables are to be omitted. The variables which affect the performance of the DMUs are selected as inputs while the benefits reaped from operation of DMUs are selected as outputs. Often, few variables offer difficulty as to identify them as inputs or outputs. Larger number of inputs and outputs may result in a greater number of DMUs getting a value of 1, thus making it difficult to evaluate with reference to the other units [20]. Availability of data, Relevant to electricity distribution and Accuracy are the three factors that has to be considered when selecting input and output variables [2], [21]–[25]. In this work, six inputs and two outputs model is considered as shown in Fig. 5 The arrow heading into DMU are inputs, in crores (red colored circles) and the arrow heading away from DMU are energy sold and collection efficiency will be the outputs in MkWh and percentages respectively (blue colored circles).

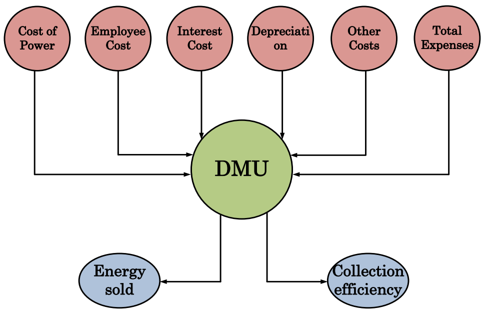

Fig. 5. Inputs and outputs considered in this work

Orientation: Efficiency can be evaluated either on input oriented or output oriented basis. In the current work, the input-orientation measure has been utilized to determine the efficiency score of 55 DMUs for the year 2018–2019 [26].

Data Collection: Data was collected for 55 DMUs in India spread in 28 states for the 2018-2019 which are operating under the management of state-owned unbundled distribution, private unbundled, joint ventures, state owned bundled utilities etc.

The physical data for various utilities is obtained from PFC Report 2018-2019. The statistical data and the correlation between input and output variables for the 2018-2019 is depicted in Table I and Table II respectively. The statistical analysis is useful procedure to examine relationships between the input and output and is measured in the metrics of mean, sum, standard deviation, minimum, maximum and range. From Table I, it is observed that the data set has a wide variation of input and output variables among the DMUs and is expected to produce accurate results.

Table II gives the correlation between input and output variables, which is the key aspect in obtaining the valid results of DEA models.

TABLE I: STATISTICS OF ELECTRIC DISTRIBUTION UTILITIES FOR 2018-2019

S. No.	Variables	Mean	Sum	Std Deviation	Min.	Max.	Range
1	Cost of Power	10027.91	551535	10868.26	314	63426	63112
2	Employee Cost	1032.82	56805	1465.85	78	8905	8827
3	Interest Cost	866	47630.2	1393.72	0.1	8248	8247.9
4	Depreciation	397.95	21887.3	532.81	0.1	2945	2944.9
5	Other Costs	631.87	34753	1099.65	14	7958	7944
6	Total Expenses	12956.56	712611	14543.6	449	83789	83340
7	Net Energy Sold in MU	16669.09	916800	18599.16	381	110178	109797
8	Collection Efficiency in %	92.84	5106.36	7.36	75.71	100	24.29

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	1							
Employee Cost	0.7804	1						
Interest Cost	0.7838	0.8688	1					
Depreciation	0.9316	0.8565	0.8710	1				
Other Costs	0.7668	0.4285	0.5389	0.7402	1			
Total Expenses	0.9932	0.8310	0.8418	0.9586	0.7706	1		
Net Energy Sold	0.9901	0.8083	0.7973	0.9498	0.7717	0.9910	1	
Collection Efficiency	0.0261	0.1056	0.0550	0.1579	0.0529	0.0452	0.0777	1

TABLE III: CCR/BCC RESULT ANALYSIS FOR THE 2018-2019

DMU Number/Name	CCR Model			BCC Model			S.E	Input Slack Total Expenditure (Rs. in crores) based on BCC Model	RTS/(Efficient/ Inefficient)
	TE (CRS Score)	Benchmark/ Peers	Number of Peers	PTE (VRS Score)	Benchmark/ Peers	Benchmark/ Peer Count			
Eastern regional grid electricity distribution utilities(09)									
1 _ NBPDCL	0.7158	26,28,45,50	4	0.7532	9, 15, 28, 47, 50	5	0.9503	650.92	DRS/ Inefficient
2_ SBPDCL	0.6598	5,45,50	3	0.8206	15,43,47	3	0.8041	738.07	DRS/ Inefficient
3_ JBVNL	0.816	5,45,50	3	0.8161	5,45,50	3	0.9999	453.52	CRS/ Inefficient

4_ CESU	0.9189	5,6,55	3	1	-	-	0.9189	0	DRS/ Inefficient
5_ NESCO	1	-	-	1	-	-	1	0	CRS/ Efficient
6 _SOUTHCO	1	-	-	1	-	-	1	0	CRS/ Efficient
7 _WESCO	1	-	-	1	-	-	1	0	CRS/ Efficient
8 _WBSEDCL	0.749	5,50	2	0.914	43,47,54	3	0.8194	1176.02	DRS/ Inefficient
9 _Sikkim PD	1	-	-	1	-	-	1	0	CRS/ Efficient
Eastern regional grid electricity distribution utilities average of TE (CRS Score) : 0.8732 DMUs less than national average: 04 out of 09				Eastern regional grid electricity distribution utilities average of PTE(BCC Score): 0.9226 DMUs less than national average: 03 out of 09					
North eastern regional grid electricity distribution utilities(07)									
10 _APDCL	0.64	5,33,45	3	0.8678	7,14,20,50	4	0.7375	269.77	DRS/ Inefficient
11 _MePDCL	1	-	-	1	-	-	1	0	CRS/ Efficient
12 _MSPDCL	1	-	-	1	-		1	0	CRS/ Efficient
13 _TSECL	0.7052	5,12,14,33	4	0.711	5,12,14,33	4	0.9918	231.97	CRS/ Efficient
14 _Arunachal PD	1	-	-	1	-	-	1	0	CRS/ Efficient
15 _Mizoram PD	1	-	-	1	-	-	1	0	CRS/ Efficient
16_Nagaland PD	1	-	-	1	-	-	1	0	CRS/ Efficient
North eastern regional grid electricity distribution utilities average of TE (CRS Score): 0.9064 DMUs less than national average: 02 out of 07				North eastern regional grid electricity distribution utilities average of PTE(BCC Score): 0.9338 DMUs less than national average: 02 out of 07					
Northern regional grid electricity distribution utilities(17)									
17 _BRPL	0.7757	5,45,50	3	0.8395	15,43,47,50	4	0.924	1161.03	DRS/ Inefficient
18 _BYPL	0.7987	5,45,50	3	0.8388	5,15,43,50	4	0.9522	1042.86	DRS/ Inefficient
19 _TPDDL	0.7158	5,45,50	3	0.7724	15,43,47,50	4	0.9268	427.18	DRS/ Inefficient
20 _DHBVNL	0.8653	5,28,33,50	4	1	-	-	0.8653	0	DRS/ Inefficient
21 _UHBVNL	0.6627	5,50	2	0.8332	14,20,43,47	4	0.7954	878.49	DRS/ Inefficient
22 _AVVNL	0.6985	5,50	2	0.7155	5,43,50	3	0.9763	1730.9	DRS/ Inefficient
23 _JdVVNL	0.7372	5,50,55	3	0.7535	43,50,55	3	0.9784	2132.3	DRS/ Inefficient
24 _JVVNL	0.7476	5,50	2	0.7743	43,50,54	3	0.9656	2449.56	DRS/ Inefficient
25 _DVVNL	1	-	-	1	-	-	1	0	DRS/ Inefficient
26 _KESCO	1	-	-	1	-	-	1	0	CRS/ Efficient
27 _MVVNL	0.7804	5,28,50	3	0.7827	5,28,45,50	4	0.997	492.37	CRS/ Efficient
28 _PaVVNL	1	-	-	1	-	-	1	0	CRS/ Efficient
29 _PuVVNL	0.9672	25,50	2	0.9687	25,28,50	3	0.9985	547.09	CRS/ Efficient
30 _UPCL	0.9597	5,45,50	3	0.9659	5,9,45,50	4	0.9937	334.98	DRS/ Inefficient
31 _HPSEBL	0.8454	45,55	2	1	-	-	0.8454	0	DRS/ Inefficient
32 _PSPCL	0.9062	45,55	2	1	-	-	0.9062	0	DRS/ Inefficient
33 _JKPDD	1	-	-	1	-	-	1	0	CRS/ Efficient
Northern regional grid electricity distribution utilities average of TE (CRS Score): 0.8506 DMUs less than national average: 09 out of 17				Northern regional grid electricity distribution utilities average of PTE(BCC Score): 0.8967 DMUs less than national average: 08 out of 17					
Southern regional grid electricity distribution utilities(12)									
34 _APEPDCL	0.6706	5,50,55	3	0.7076	4,43,50	3	0.9476	536.24	DRS/ Inefficient
35 _APSPDCL	0.6319	45,50,55	3	0.8072	20,42,50,54	4	0.7829	1216.47	DRS/ Inefficient
36_BESCOM	0.714	5,45,50,55	4	0.8184	20,28,32,42, 50	5	0.8724	20.35	DRS/ Inefficient
37_CHESCOM	0.8717	5,50,55	3	0.881	5,43,50,55	4	0.9894	144.8	DRS/ Inefficient
38_GESCOM	0.8431	5,50,55	3	0.8489	5,43,50,55	4	0.9932	202.72	DRS/ Inefficient
39 _HESCOM	0.8008	5,50,55	3	0.8278	5,43,50,55	4	0.9674	423.56	DRS/ Inefficient
40 _MESCOM	0.9263	5,50	2	0.93	5,43,50	3	0.996	152.1	DRS/ Inefficient
41 _TSNPDCL	0.7689	45,55	2	0.8418	33,45,50	3	0.9134	1341.3	CRS/ Efficient

42 _TSSPDCL	0.8428	33,45	2	1	-	-	0.8428	0	DRS/ Inefficient
43 _KSEBL	0.9754	6,55	2	1	-	-	0.9754	0	DRS/ Inefficient
44 - TANGEDCO	0.8042	45,55	2	1	-	-	0.8042	0	DRS/ Inefficient
45 _Puducherry PD	1	-	-	1	-	-	1	0	CRS/ Efficient
Southern regional grid electricity distribution utilities average of TE(CRS Score): 0.8208 DMUs less than national average: 08 out of 12				Southern regional grid electricity distribution utilities average of PTE(BCC Score): 0.8885 DMUs less than national average: 07 out of 12					
Western regional grid electricity distribution utilities(10)									
46 _CSPDCL	0.7672	5,45,50,55	4	0.8396	28,33,50	3	0.9138	1197.39	CRS/ Efficient
47 _DGVCL	1	-	-	1	-	-	1	0	CRS/ Efficient
48 _MGVCL	0.9029	45,50,55	3	0.9466	14,15,43,50, 55	5	0.9538	187.73	DRS/ Inefficient
49 _PGVCL	0.9291	5,50	2	1	-	-	0.9291	0	DRS/ Inefficient
50 _UGVCL	1	-	-	1	-	-	1	0	CRS/ Efficient
51_MPMaKVVCL	0.677	5,50	2	0.6831	5,43,50	3	0.991	1804.66	DRS/ Inefficient
52 _MPPaKVVCL	0.842	5,50	2	0.9126	4,43,50	3	0.9226	1789.71	DRS/ Inefficient
53 _MPPoKVVCL	0.7324	5,50	2	0.7459	5,43,50	3	0.9819	1226.62	DRS/ Inefficient
54 _MSEDCL	0.8323	5,50	2	1	-	-	0.8323	0	DRS/ Inefficient
55 _Goa PD	1	-	-	1	-	-	1	0	CRS/ Efficient
Western regional grid electricity distribution utilities average of TE (CRS Score): 0.8682 DMUs less than national average: 05 out of 10				Western regional grid electricity distribution utilities average of PTE(BCC Score) : 0.9127 DMUs less than national average: 03 out of 10					
National Average TE (CRS Score): 0.8581 DMUs less than National average: 28 out of 55 Number of Efficient(having score of 1) DMUs: 17 out of 55				National Average PTE (CRS Score): 0.9075 DMUs less than National average: 23 out of 55 Number of Efficient (having score of 1) DMUs:26 out of 55 Input Slack Total Expenditure (Rs. in crores): 24,960.68					

IV. RESULTS & DISCUSSION

For comprehensive performance assessment of the Indian Electricity Distribution Utilities (IEDUs), six inputs and two outputs, as described in Table I, have been considered. The performance analysis has been considered with two different scales, CRS and VRS, with input orientation. The results are indicated in Table III. The technical efficiency is measured by CCR model with CRS assumption and pure technical efficiency is measured using BCC model with VRS assumption. The technical efficiency, Pure Technical efficiency, and Scale efficiency, frequency of use as peer/reference group by inefficient DMU of CCR & BCC models, average Technical Efficiency using CCR and BCC models are being computed and the results discussed in the following sections.

A. Technical Efficiency (TE) Result-CCR Model

The technical efficiency (TE) result is computed using CCR model assuming constant returns to scale. The following points were observed from Table III and Fig. 6.

- The utilities display significant variation in Technical efficiency levels.
- The Technical efficiency (TE) has a national mean score of 0.8581 for all the utilities and having with 14.19% inefficiency.
- Out of 55 DMUs, 17 DMUs are efficient and the rest 38 are inefficient.

It can be inferred that 17 DMUs emerged with best practices by attaining technical efficiency of 1 can be considered as peers/benchmark for 38 inefficient DMUs to improve their performance. For example, for the inefficient utility DMU-2 i.e. SBPDCL (Bihar), the technical efficiency score is 66%. For this utility, three peers /benchmark utilities (03) are DMUs-5, 45, 50.

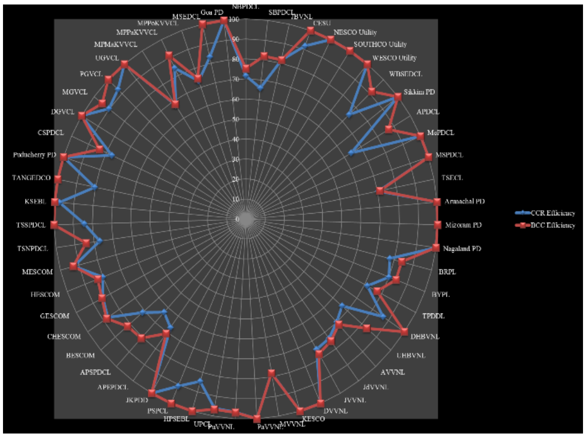

Fig. 6. CCR/BCC efficiency analysis for the 2018-2019

B. Pure Technical Efficiency Result-BCC model

The BCC based pure technical efficiency result can also be observed in Table III and Fig. 6. It is evident, that the utilities display significant variation in pure technical efficiency levels. The Technical efficiency had a mean score of 0.9075 for all the utilities. It can be inferred that 26 DMUs emerged with best practices by attaining technical efficiency of 1 and can be considered as benchmark for 29 inefficient DMUs to improve their performance. For example, for the inefficient utility

DMU-2 i.e. SBPDCL (Bihar), the technical efficiency score is 82.06%. For this utility, the reference utilities (03) are DMUs-15, 43, 47.

It is interesting to note that the eight (08) DMUs numbered 4, 20, 31, 42, 43, 44, 49, 54, i.e., CESU (0.9189), DHBVNL (0.8653), HPSEBL (0.8454), TSSPDCL (0.8428), KSEBL (0.9754), TANGEDCO (0.8042), PGVCL (09291) and MSEDCL (0.8323) have relatively low CRS scores, but obtained unit VRS score. This clearly shows that these 08 DMUs can convert its inputs into outputs.

C. Computation of Scale Efficiency (SE)

From Table III and Fig. 6, the 17 DMUs are scale efficient as they have the value of their SE scores equal to one. They are operating at the optimal scale and there is no adverse impact of scale size on their performance. Also, 38 DMUs are found to be scale inefficient. These 38 DMUs are either too big or too small relative to their optimal size. The lowest SE is obtained for the DMU 10 i.e., APDCL having with 0.7325.

The different 34 DMUs exhibit decreasing return to scale (DRS) suggesting that these utilities exceeded their most productive scale size (MPSS). This outcome supports the unbundling and the Benchmark utilities have been identified for respective inefficient utility.

It is also observed from Table III and Fig. 7 that result of slack analysis is found that the total expenses Rs. 24,960.68 crores by which an input is overused. From the results, it is observed that the employment of rural electrification with cost efficient distributed generation and micro grid by deploying the renewable sources instead of a centralized grid improves system performance in terms of total expenditure. In addition to this, it also enhances the socio-economic development of rural India.

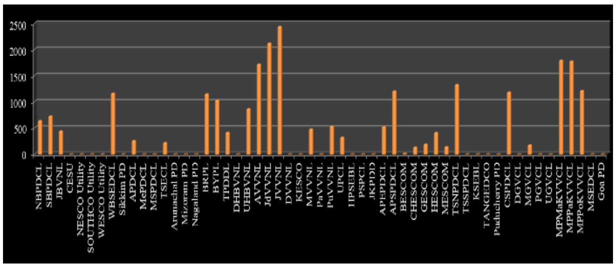

Fig. 7. Input slacks of total expenditure of utilities in Rs. crores based on BCC model for2018-2019.

The Fig. 8 shows the average technical efficiencies of electric distribution utilities based on regional grid computed with CCR and BCC models. It can be observed that the Northeastern regional grid has the highest efficiency at 90.64% (93.98%) compared to other regional grids while the Southern regional grid has an efficiency of 82.08% (89.67%). The national average efficiency for entire country can be observed to be 85.81% (90.75%). It is clearly noticed that a total of 28(23) electricity distribution utilities have their technical efficiencies below the national average technical efficiencies when computed with CRR (BCC) models.

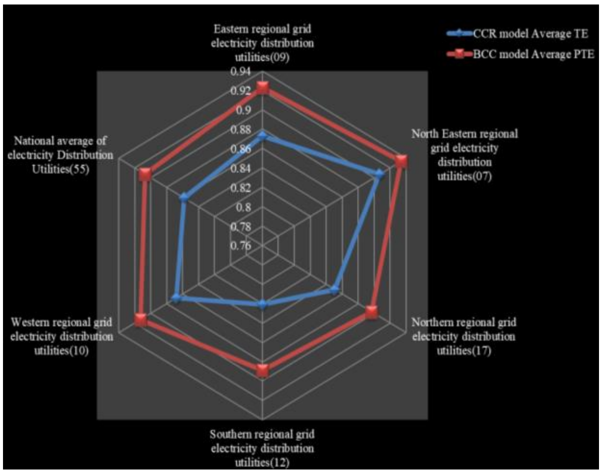

Fig. 8. CCR and BCC Average Technical Efficiency of utilities based on regional grid for 2018-2019.

D. Frequency of Use as Peer/Benchmark Group by Inefficient DMU-CCR & BCC Model

It can be noticed from the Table IV and Fig. 9 that the frequency of UGVCL-WR & NESCO–ER appearing in the peer/benchmark set of efficient DMUs is 29 using CCR model, which is relatively more frequent count. It can be regarded as a Role model in the Indian electricity distribution utilities. On the other hand, MSPDCL-ER, Arunachal PaDVVNL-NR, KESCO have a very low frequency (01) of appearing in the reference sets of inefficient DMUS. Therefore, they can be considered as marginally robust DMUS in exemplifying best practices to be followed by inefficient-DMUS to enhance their efficiency levels.

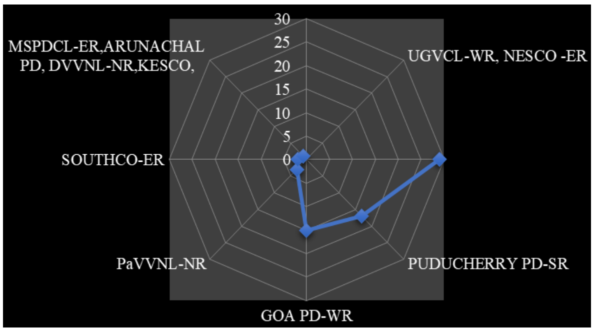

Fig. 9. CCR model Frequency of use as peer/benchmark group by inefficient DMU for 2018-2019.

TABLE IV: FREQUENCY OF USE AS PEER GROUP BY INEFFICIENT DMU WITH CCR AND BCC MODELS

CCR Model			**BCC Model**		
Name of the DMU/State	Efficient DMU for 2018-2019	Frequency of use as peer/group by inefficient DMU	Name of the DMU/State	Efficient DMU for 2018-2019	Frequency of use as peer/group by inefficient DMU
UGVCL-WR, NESCO -ER	50, 5	29	UGVCL-WR	50	25
PUDUCHERRY PD-SR	45	17	KSEBL-SR	43	19

GOA PD-WR	55	15	NESCO-ER	5	12
PaVVNL-NR	28	3	DGVCL-WR Mizoram PD-NE	47, 15	6
SOUTHCO-ER	6	2	PaVVNL-NR, Goa PD	28, 55	5
MSPDCL-ER, ARUNACHAL PD, DVVNL-NR, KESCO,	12, 14, 25, 26	1	Arunachal PD-NE, DHBVNL-NR, PUDUCHERRY PD-SR	14, 20, 45	4
--	---	---	JKPDD-NR, MSEDCL-WR	33, 54	3
---	---	---	SESU-ER,Sikkim PD, TSSPDCL	4, 9, 42	2
----	---	----	WESCO, MSPDCL, DVVNL, PSPCL	7,12,25,32	1
Total Benchmark/peer DMUs are 10			Total Benchmark/peer DMUs are 19		

TABLE V: AVERAGE TECHNICAL EFFICIENCY OF ELECTRICITY DISTRIBUTION UTILITIES BASED ON REGIONAL/NATIONAL GRID BASIS FOR THE 2018-2019

DMUs on Regional basis	CCR model Average TE		BCC model Average PTE	
	CCR model Average TE	Number of DMUs below National average	BCC model Average PTE	Number of DMUs below national average
Eastern regional grid electricity distribution utilities (09)	0.8732	04 out of 09	0.9226	03 out of 09
Northeastern regional grid electricity distribution utilities (07)	0.9064	02 out of 07	0.9338	02 out of 07
Northern regional grid electricity distribution utilities (17)	0.8506	09 out of 017	0.8967	08 out of 17
Southern regional grid electricity distribution utilities (12)	0.8208	08 out of 012	0.8885	07 out of 12
Western regional grid electricity distribution utilities (10)	0.8682	05 out of 10	0.9127	03 out of 10
National average of electricity Distribution Utilities (55)	**0.8581**	**28 out of 55**	**0.9075**	**23 out of 55**

From the Table V, it is evident that national average technical efficiency is 0.8581with CCR model and is 0.9075 with BCC model. From the Table III, it can be observed that 50.9% (28 out of 55) & 41.81% (23 out of 55) DMUs in India are operating with less than national average of CCR &BCC Technical efficiency. It is further observed that the southern regional grid electricity distribution utilities are having lowest average technical efficiency of 0.8208 and northeast regional grid DMUs are having highest average technical efficiency of 0.9338. From the Table IV, Fig. 9 and Fig. 10, the frequency of UGVCL appearing in the reference set of efficient DMUS is 29 and 25 based on CCR & BCC models, which is relatively more frequent count. On other hand more frequency of UGVCL (western), KSEB (southern), NESCO (eastern), PaVVNL (northern) and Mizoram PD (northeastern) respectively appearing in the reference set of efficient DMUs and can be considered as a Role model in respective regional electricity grid basis. The assessment, although was performed based on single year data of 2018-2019.

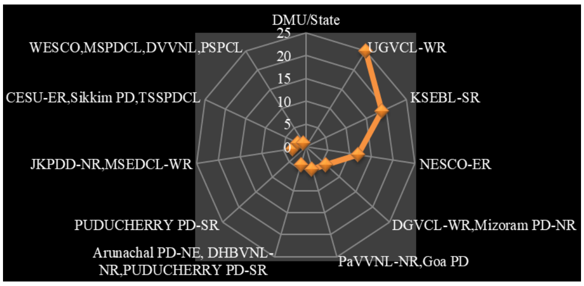

Fig. 10. BCC model frequency of use as peer/benchmark group by inefficient DMU for 2018-2019

Whereas it can be noticed from the Table IV and Fig. 10 that the frequency of UGVCL appearing in the reference set of efficient DMUS is 25 using BCC model, which is relatively more frequent count. Similar to CCR model, the same utility also emerged as leader in BCC model among the Indian electricity distribution Utilities. On the other hand, WESCO, MSPDCL, DVVNL, PSPCL have a very low frequency (01) of appearing in the reference sets of inefficient DMUS. Therefore, they can be considered as marginally robust DMUs in exemplifying best practices to be followed by inefficient-DMUs to enhance their efficiency levels.

E. Comparison between CCR and BCC Models

The relative performance of the CCR and BCC models in terms of the parameters of 55 Indian Electricity Distribution utilities (DMUs) for the year 2018-2019 is being compared and presented in Table VI.

TABLE VI: COMPARISON BETWEEN CCR AND BCC MODELS

S. No.	Parameter	CCR model	BCC model	Remarks
1	Efficient DMUs	17 out of 55	26 out of 55	It is interesting to note that the nine (09) DMUs numbered 4, 20, 31, 32, 42, 43, 44, 49, 54, i.e., CESU (0.9189), DHBVNL (0.8653), HPSEBL (0.8454), PSPCL (0.9062), TSSPDCL (0.8428), KSEBL (0.9754), TANGEDCO (0.8042), PGVCL (09291) and MSEDCL (0.8323) have relatively low CRS scores but obtained unit VRS score.
2	Inefficient DMUS	38 out of 55	29 out of 55	Lower number of units are identified as inefficient in BCC model as the scale inefficiency is ignored.
3	National Mean Score	0.8581	0.9075	The National Mean Score is more by 0.0494 for the BCC model.

4	Number of DMUs below the National Mean Score	28 out of 55	23 out of 55	Lower number of units are identified in BCC model as the scale inefficiency is ignored.
5	Total Benchmarks/ peer DMUs	10 out of 55	19 out of 55	Since scale efficiency is ignored in BCC model, more efficient DMUs have surfaced.

V. Conclusion

The main objective of this work is to determine the relative performance of 55 Indian Electricity Distribution utilities (DMUs) for the 2018-2019. The performance of utilities has been computed by applying DEA. The CCR and BCC models of DEA frontier have been applied to assess the overall efficiency, technical and scale efficiency of 55 Indian electricity distribution utilities. The results show that only 17(26) DMUs are identified as efficient utilities across the country with CCR (BCC) models. The remaining 38(29) DMUs are inefficient because of inappropriate scale of operation and lack of pure technical efficiency with CCR (BCC). To improve the performance of such inefficient DMUs, initiatives such as procurement of cost-efficient power and reducing distribution cost can be implemented. These can be achieved by creating competition with introduction of multiple licensees within the geographical area and attracting huge capital investment for integration of information and communication technologies which include deploying smart electricity distribution prepaid meters. Besides technical and commercial losses can be reduced by upgrading the technology of distribution infrastructure. It is strongly recommended to identify the specific areas and determine the root causes underlying inefficiencies and robustness of electricity distribution utilities in southern regional grid and India as most of the utilities in southern grid are performing poor when compared to the utilities in the other regional grids.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Both the authors equally contributed to the work by analyzing the performance of electric distribution utilities in India with objective to determine the relative performance and presented in the paper by preparing and approving the final draft of the manuscript.

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