EFFICACY EVALUATION OF INDIAN POWER SECTOR RESTRUCTURING POLICY FRAMEWORK

A THESIS

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CANDIDATE'S DECLARATION

I hereby certify that work which is being presented in the thesis entitled **EFFICACY EVALUATION OF INDIAN POWER SECTOR RESTRUCTURING POLICY FRAMEWORK** in partial fulfillment of the requirements for the award of the **Degree of Doctor of Philosophy** and submitted in the **Department of Electrical Engineering** of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July 2007 to December 2010 under the supervision of Dr. Hari Om Gupta and Dr. Narayana Prasad Padhy, Professors, Department of Electrical Engineering, Indian Institute of Technology Roorkee, Roorkee.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

(Vinod Kumar Yadav)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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6/8/2011

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ABSTRACT

Presently Electricity sector across the developing countries is under the process of restructuring and adopting the deregulatory structure for providing choice, quality and economic service to the consumers. The motive behind this structural change is to create some sort of electricity market and thereby introducing competition in the power sector. India is no exception to this and the power industries in India are undergoing a state of transformation.

In India, State Electricity Boards (SEBs) are beset with unsustainable inefficiencies, unviable tariffs, high Transmission and Distribution (T&D) losses, mounting subsidies, lack of adequate attention to the distribution segment, wasteful practices and lackadaisical financial management. All these factors led to the financial fragility of the entire power sector. Due to the uninspiring financial position of the vertically integrated monolithic SEBs, the power sector was failing to attract the much needed investments for its development. The Indian power sector commenced an era of reform and restructuring since the year 1991 after the opening of the sector for Independent Power Producers (IPPs). Thereafter, enactment of the Electricity Act, 2003 introduced innovative concepts like power trading, open access, appellate tribunal etc. and special provisions for the rural areas electrification. The Act also envisions a phase shift in the reform process, providing a necessary impetus to the sagging momentum for distribution reforms in the country. Though reforms have been implemented by most of the states, power sector continued to render unsatisfactory performance as the attention was focused on generation expansion programs mainly, neglecting the distribution sector. As a result, the distribution segment as a whole has lagged, in terms of both operation efficiency and financial performance. The financial performance of Indian Power utilities is severely hampered by low Return on Investments (RoI) and poor collection recovery from the consumers. This situation is further aggravated by poor operational efficiency. Realizing the need to accelerate the reforms in the distribution sector, the central

government introduced Accelerated Power Development & Reforms Program (APDRP) for urban areas with the objective to improve the financial viability of state power utilities, reducing Aggregate Technical and Commercial (AT & C) losses, improving customer satisfaction, and increasing the reliability and quality of the power supply.

In this scenario, it is being viewed with paramount importance to evaluate the performance of the distribution utilities and identify the scope for improvement in efficiency of various states, carrying out an intra state analysis. Data Envelopment Analysis (DEA) is one of the most widely used analytical approach for carrying out this analysis.

The concept of measurement of utility efficiencies for the electricity distribution divisions has so far not investigated in India. The present work explores and establishes the need for measurement of performances in the context of the ongoing electricity reforms in India. This study evaluates the performance of Electricity Distribution Divisions (EDDs) of an Indian state power utility namely Uttarakhand Power Corporation Limited (UPCL) in terms of overall efficiency through application of input oriented DEA, a non-parametric approach to frontier analysis, with an objective to trace the effectiveness of ongoing restructuring process. Relative efficiencies of the divisions are compared for the period 2005-2008. Notably, production technology might have changed during the period of analysis. Therefore, further using Malmquist Productivity Index (MPI) and its decompositions, productivity change (efficiency change and frontier shift) is investigated for EDDs. Decrease in efficiency is observed during period of analysis. To investigate the root cause of decrease in efficiency during restructuring process, performance of EDDs for the year 2007 is examined in terms of overall efficiency, technical efficiency and scale efficiency. Since data can be contaminated by statistical noise, an obvious question could be: to what extent can perturbations in the data observations are tolerated before an efficient DMU is misclassified as inefficient. Hence, reliability of the CCR efficient divisions is examined for the same year. Slack analysis is carried out to formulate improvement directions for relatively inefficient divisions. Slack analysis identifies the scope for possible reduction in operating and maintenance (O&M) costs and number of employees. The results have been discussed in the context of policy alternatives and related issues in the Indian electric distribution sector. A sensitivity analysis has also been carried out to explore the type of inefficiencies prevalent in the divisions and to identify the factors that are advantageous for the inefficient divisions in efficiency improvement.

In the year 2007, most of the inefficient divisions suffered from scale inefficiency to greater extent than technical inefficiency, thus different reorganization alternatives are investigated to enhance the efficiency of inefficient divisions. To improve the operational efficiency of EDDs, UPCL disintegrated several divisions into smaller ones over period 2005-2008. However, micro level examination revealed the ineffectiveness of this process. Therefore, in the present work an alternative model for selecting the EDDs for disintegration and for selecting the optimum scale for disintegration of EDDs is proposed based on the efficiency analysis of 2007. Thereafter, the model is verified by comparing the mean efficiency of the EDDs derived using proposed model with that of existing ones. Further, the result of analysis based on simple radial efficiency is re-evaluated with the introduction of cross efficiency measures in DEA to bring forth the true performance of divisions. Cross efficiency evaluation differentiates the true "overall efficient" divisions from "false positive" divisions which can be termed as apparent efficient ones. A difficulty with a linear combination of DMUs as the reference set in DEA is that, an inefficient DMU and its reference set may not be inherently similar in their practices. Therefore, it is possible that in some cases the reference targets may be unattainable goals for the inefficient DMUs. Thus, hierarchical clustering approach is adopted to effectively group similar distribution divisions; this technique can herald realistic targets for poorly performing EDDs to improve the efficiency. In this method Pearson correlation coefficient between pairs of column in a Cross Efficiency Matrix (CEM) is calculated. This parameter describes the degree of similarity in the EDDs and hence using these correlation coefficients as the elements in a resemblance matrix and thereafter executing a clustering analysis using complete linkage method yields different clusters of divisions with similar practices. Divisions with the highest column mean in a cluster can be used as the primary benchmark for the other EDDs in that cluster.

A benchmark-share measure is also developed for technically efficient divisions in order to further characterize the performance of efficient ones and to yield information on the role of each efficient division played in benchmarking inefficient divisions and also to identify the best EDDs in terms of the benchmark-share. The bigger the benchmark share, the more important an efficient division is in benchmarking. The result analysis is envisaged to be instrumental to policy makers and managers to increase the operational efficiency of the EDDs leading to higher profitability of the state electricity board. It can provide a platform for initiating benchmarking in a regulatory regime.

Though the field of performance evaluation in the electricity sector is the vast area of study, the present work tries to fill-in some research gaps. The subject matter addressed in the present work is relevant for the policy makers to implement an effective restructuring process of power sector in India and other countries.

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(Vinod Kumar Yadav)

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LIST OF SYMBOLS

The symbols used in the text have been defined at appropriate places, however, for easy reference, the list of symbols is given below.

Symbols	Explanation
θ	The relative efficiency score
y_{rj}	The amount of output r produced by DMU j
x_{ij}	The amount of input i utilized by DMU j
v_r	The weight given to the output r
u_i	The weight given to the input i
N	Total number of DMUs
M	Total number of inputs
S	Total number of outputs
O	Designation unit for an optimization run
λ_j	Weights in the dual model for the inputs and outputs of the n units
s_{io}^-	Input slack
s_{ro}^+	Output slack
E_{po}	Cross efficiency of DMU_o using the weighting scheme of DMU_p
E_{oo}	Efficiency score for DMU_o using its own weighting scheme
e_o	Mean cross efficiency of the DMU_o
E	Index sets for the VRS efficient EDDs
N	Index sets for the VRS inefficient EDDs
Δ_j^k	k^{th} input-specific benchmark-share measure for each VRS efficient EDD_j
Π_j^q	q^{th} output-specific benchmark-share measure for each VRS efficient EDD_j
α^* and β^*	Optimal values

LIST OF ABBREVIATIONS

The abbreviation used in the text have been defined at appropriate places, however, for easy reference, the list of abbreviations is given below.

Abbreviation	Explanation
ABT	Availability Based Tariffs
ADB	Asia Development Bank
A&G	Administrative and General
ANOVA	Analysis of Variance
AP	Annual Plan Estimates
APDRP	Accelerated Power Development & Reforms Program
AT & C	Aggregate Technical and Commercial
BCC	Banker, Charnes and Cooper
CAA	Clean Air Act
CAC	Central Advisory Committee
CCR	Charnes, Cooper and Rhodes
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CEM	Cross Efficiency Matrix
CERC	Central Electricity Regulatory Commission
CGS	Central Generating Station
CRS	Constant Return to Scale
CTU	Central Transmission Utility
DEA	Data Envelopment Analysis
DEAP	Data Envelopment Analysis Program
DFID	Department for International Development
DMUs	Decision Making Units
DSM	Demand Side Management
EDCs	Electricity Distribution Circles
EDDs	Electricity Distribution Divisions
EMC	Energy Management Center
E&E	Energy and Environmental

FPI	False Positive Index
FYP	Five Year Plan
GENCOS	Generating Companies
GW	Giga Watts
GWH	Giga Watts Hour
HT	High Tension
IPPs	Independent Power Producers
IT	Information Technology
km	Kilometre
kV	Kilo Volt
kVA	Kilo Volt Ampere
LP	Linear Programming
LT	Low Tension
MoP	Ministry of Power
MPI	Malmquist Productivity Index
MPSS	Most Productive Scale Size
MYT	Multi-Year Tariff
MW	Mega Watt
NHPC	National Hydro Power Corporation
NLDC	National Load Dispatch Center
NPTI	National Power Training Institutes
NTPC	National Thermal Power Corporation
OE	Overall Efficiency
O&M	Operating and maintenance
PFC	Power Finance Corporation
PGCIL	Power Grid Corporation of India Limited
PTC	Power Trading Corporation
PTCUL	Power Transmission Corporation of Uttarakhand Limited
PTW	Private Tube-Well
RCM	Reliability Centered Maintenance
RE	Revised Estimates
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RLDC	Regional Load Dispatch Center
RoI	Return on Investment

RoR	Rate of Return
R&M	Repairing and Maintenance
SAC	State Advisory Committee
SDC	State Distribution Company
SE	Scale Efficiency
SEBs	State Electricity Boards
SERCs	State Electricity Regulatory Commissions
SOEUs	State Owned Electric Utilities
STU	State Transmission Utility
TE	Technical Efficiency
TFP	Total Factor Productivity
T&D	Transmission and Distribution
UERC	Uttarakhand Electricity Regulatory Commission
UJVNL	Uttarakhand Jal Vidyut Nigam Limited
UNFCCC	United Nations Framework of Climate Change Convention
UPCL	Uttarakhand Power Corporation limited
UREDA	Uttarakhand Renewable Energy Development Agency
USEB	Uttarakhand State Electricity Board
VRS	Variable Return to Scale

Chapter-1
INTRODUCTION

1.1 GENERAL

Electric power is an essential commodity in the modern era for enjoying the quality of life, at the same time it is an indispensable input for economic and social development. Hence electricity sector deregulation and restructuring are now on the policy agenda in both the developed and developing countries in order to draw private capital and increase competition to meet the growing demand of electricity economically [10, 15]. Electricity sector reforms are transforming the structure and operating environments of electricity industries across a host of countries [143] with the aim to promote utilities efficiency through effective competition and to enable renewable and efficient energy to make major contribution to future energy provisions. These changes aim to benefit consumers with affordable, diverse, and sustainable electricity for the future [42]. Although the effects of such reforms in a number of developed economies are now being widely documented, yet, apart from a few case studies, the experiences of developing countries remain much less researched [155]. Nonetheless, the later is important not just because such studies would reflect concerns that affect millions of poor, but also because privatization, competition and regulatory reforms are the themes of a wide majority of donor aid programs, notably of the World Bank [53]. It is for these reasons that such documentation is urgently required for the Indian electricity sector that is currently undergoing reforms.

1.2 REFORMS IN DEVELOPING COUNTRIES

The driving forces behind electricity sector reform differ considerably between developed and developing countries. In mature industrial countries, pressure for change has grown with the emergence of excess capacity and from disillusionment with capital-intensive generation projects triggered by the oil crises of the 1970s [60]. In developing and transition countries, the reforms have been forced by the unsatisfactory operating and financial performances (with low labor productivities, poor service qualities, and high system losses) of state-owned electricity systems, lack of public funds for much needed investments, unavailability of service for large portions of the population, and government desire to raise revenue through privatization [57, 121, 145]. All developing countries want to level up with the developed and industrialized countries and therefore power demands are increasing at a rapid pace, to enable them to progress fast and achieve heavy industrialization [35]. Huge demand-supply gap is often universal problem in developing countries and the distribution are frequently financially crippled [106, 139]. Serious cash flow constraints result in palpable curtailment of much needed investments in expansion and maintenance of service and ultimately manifest in poor sector performances. High distribution losses, poor managements, low market densities, poor metering and billing practices, and weak institutions are some of the common problems besieging the electricity sector across developing nations [9], and metering of power sector were realized lately [97]. All these factors have contributed to initiation and acceleration of reforms in developing countries. Fig. 1.1 represents T&D losses for developed and developing countries. While electricity consumption are on the rise globally, the annual growth rates are far higher in developing countries, and especially in China, India and few countries in South America. The fast growing developing economies need more power, and hence require massive investments in generation, transmission, and distribution. To attract the necessary investment, the developing countries are trying to make their electricity sector work on the market principles, by introducing sector-wide reforms, and by appropriate induction of efficiencies in the operations of electric utilities. With changes in supply and demand patterns, increased interconnection, and stricter environmental constraints, there is a constant need for future planning of electrical networks [41]. Restructuring is expected to overcome the inefficiency prevalent in the monopoly franchise structure with assured revenue collection [55].

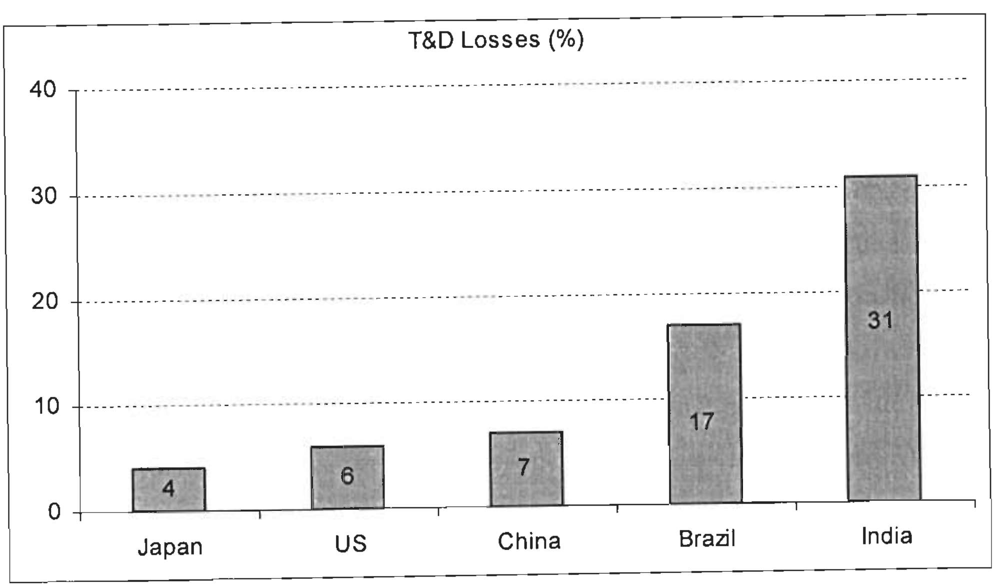


Fig. 1.1: T&D losses in developed and developing countries

1.3 THE CASE OF INDIA

Electricity today is a critical input for the growth and the socio-economic development of the country. India is ranked as the fifth largest producers of electricity in the world with an installed capacity of 152 GW as on 30 September 2009, which is about 4 percent of global power generation. The state governments account for 51.5% of the total generation capacity, while the central and private sector accounts for 33.1% and 15.4% of the generation capacity respectively. But there is a huge gap between generation and demand. The availability and supply of quality power at reasonable price is essential for inclusive and equitable growth. India ranks world's sixth energy consumer accounting for the 3.5% of the world's total annual energy consumption, but it ranks as one of the lowest country in terms of per capita consumption of power. More than 18% of villages and 45% of total households in India still do not have access to power. The peak power shortage, which was around 11-12% levels during the IXth Five Year Plan period and first few years of Xth Plan, is on increasing trend and has already 14% in the current year [51]. The high level of technical and commercial losses and lack of commercial approach in management of utilities have made the scenario worse. The government of India has under taken several reform initiatives including enactment of Electricity Act, 2003, National Electricity Policy, National Tariff Policy, Open Access in Transmission, Open Access in Distribution, initiatives for establishing Ultra Mega Power Projects envisaging super critical technology to provide much needed framework for reform oriented, competitive and commercially driven power sector. The Ministry of Power, Government of India has also launched the Restructured Accelerated Power Development and Reforms Programs (R-APDRP) during XIth Five Year Plan with clear focus on actual, demonstrable performances in terms of sustained loss reduction in distribution and provides support and financial incentives for reduction in Transmission and Distribution (T&D) losses. XIth Five Year Plan investments under this scheme are targeted to US$10 billion. Another US$10 billion is likely to be spent on rural electrification to achieve the government targets of "Power to All" by 2012. With reforms taking centre stage, it has become imperative to identify competitive segments of the value chain and separate them from naturally monopolistic elements of the value chain. For example while generally the distribution business is considered as monopolistic, separation of supply and wires functions could potentially make supply function very competitive [2].

1.4 NEED FOR THE PERFORMANCE ANALYSIS IN THE INDIAN ELECTRICITY SECTOR

Electrical energy is a world wide accepted significant parameter for measuring the economic and social prosperity of any nation. About 1.5 – 2 billion people in developing countries do not have access to the electricity and 450 million of them are in India alone [79]. Even in this scenario the Aggregate Technical and Commercial (AT & C) losses in India gnaws about 35 % of energy produced [103]. To bridge over this lacunae, India instigated reform process of its power sector in 1991 with the prime aim of meeting the ever-widening gap between the demand and availability of electricity, improving the technical performance of the State Electricity Boards (SEBs), enabling the central and state government to finance and mobilize resources for generation capacity expansion projects making third party investment in power sector imperative [110]. Comprehensive reforms of legislation including Electricity Regulatory Commission Act 1998, Electricity Bill (2000) and Electricity Act 2003 also followed [143].

All the 29 states in India have resorted to restructuring process of their respective State Owned Electric Utilities (SOEUs) and these are at various stages of implementation [117]. But even about two decades after restructuring was initiated, all these states are still facing both energy and peak demand shortage. In India with the increasing population and rapid development, energy shortage and peaking shortage are increasing with time and have elevated to 11.1% and 11.9% respectively in 2008-09 from the level of 8.1 % and 11.3% in 1997-98 [103]. The growth of power sector could not keep pace with the economic growth of the country. Though reforms have been implemented by most of the states, power sector continued to render unsatisfactory performance as the attention was focused on generation expansion programs mainly. Whereas, the reform in distribution sector should have also been given an equal or more importance as efficiency improvement measures, keeping in view that the Indian power utilities feed a very large number of consumers, located over wide area of the subcontinent [36].

Realizing the need to accelerate the reforms in the distribution sector, the central government introduced APDRP for urban areas with the objective to improve the financial viability of state utilities, reducing AT & C losses, improving customer satisfaction, and increasing the reliability and quality of the power supply. The reform linked investment component also motivated restructuring and initiation of regulatory reforms in various states [59]. There is therefore, a case for the review of performances of electric utilities, so that lessons from failures be taken note of, and effective steps be taken to mitigate shortcomings.

Such an analysis will also be of interest to the regulators in deciding the tariff and implementing incentive-based regulation to promote yardstick competition which is introduced by the enactment of the Electricity Act, 2003. For monopolistic electricity markets such as those in India, usual market indicators of performance, such as profitability and rates of return cannot be used to gauge an economic performance accurately. It is possible that these financial indicators will be more an indication of the distortions themselves rather than of the performance of the industry in question. In these circumstances, indicators of the level and changes of productivity and efficiency are more appropriate indicators of an industry's performance [95].

1.5 THE ADVANTAGE OF MEASURING PERFORMANCES

The performance of an organization can be quantified mainly in terms of efficiency and productivity, and these parameters have been the most commonly used measures of performances in the electricity sectors. The performance of power utilities in India, as in other developing countries, has been characterized by inadequate services and a general sense of dissatisfaction amongst the consumers. However, till date such inefficiencies or performances have been rarely measured.

Under these circumstances, a performance enhancing strategy to initiate improvements may incorporate wide sector reforms as initiated in a number of developing countries [154]. Performance benchmarking of utilities is an accepted measure that evaluates the success of a reforms program. Benchmarking can further help to develop strategic plans for improvements in the performances, can act as a tool for resource allocation and can lead to sustained cost reductions and efficiency improvements in the services. The improvement of efficiency of the utilities would essentially aim at providing reliable and economic power supply to the consumers by ensuring defined outputs for minimal inputs. The desire to create competitive environment is now prevailing in power industry in India but due to limited scope of competition the search for "efficiency" gains importance.

Internal efficiency improvement is win-win scenario for the existing utilities. Benchmarking the operational and financial performances will free up resources, which can bring down the overall resource requirement for utilities. A typical efficiency and productivity analysis will help power managers to identify inefficient units and also identify targets based on which incentive schemes may be devised for managers. This would also help to uncover the best practices [39] in order to evolve better competition and to set the targets.

Furthermore, the concept of introducing efficiency ensure sourcing of input at least cost, and improved management and higher efficiency as there are quantifiable goals to be achieved. The two are related since greater efficiency results in cost savings and allows greater availability of funds for investment; and also results in improved management due to performance benchmarks. Thus, performance appraisal of utilities is a primary step in the direction of ensuring sustainability in the power services.

Performance appraisal of power utilities is also necessary for:

- Gauging the efficiencies of electric utilities, ranking and assessing their performances.
- Establishing goals for performance enhancement of inefficient utilities.
- Ensuring cost minimization in power services.
- Setting targets for improvements and enable access to knowledge on best practices in order to support and drive improvement program.
- Formulating resource allocation strategies.
- Formulating performance enhancement strategies by providing planners and policymakers with necessary decision-making inputs for refinement of existing utilities.
- Regulating the sector, especially in the form incentive regulation.
- Setting rational tariffs, particularly in evolution of efficiency (X) factors.
- Ensuring the sustenance of electric utilities and the sector in the long run.

Thus, an urgent need existing for carrying out a scientific analysis of relative performance using appropriate benchmarking techniques for the Indian power supply sector. With increasing commercialization of the power supply utilities, professional management of services is likely to evolve to enhance levels. With the regulation now emerging as a mandatory provision, the performance appraisal and measurement tools will be increasingly used to identify and promote the best practices and to penalize those utilities that are inefficient. This dissertation is a step forward in this direction.

1.6 THE PRESENT WORK

The research work focuses on evaluation of the performances of the Electric utilities in India. The work is particularly significant in the context of the ongoing reforms in the Indian electricity sector that stands on the verge of a new era of liberalization, particularly after the inception of the Electricity Act, 2003.

Unfortunately, the concept of efficiency in the delivery of power services has been historically alien in the Indian context (even outside India, efficiency measurement studies are relatively rare in developing countries), and now it is being realized that efficiency evaluation is an integral components of any comprehensive reform program (the success of a reform program ultimately has to be measured and quantified). The efficiency evaluation is also necessary for generating competition in the sector and for sector regulation and scientific tariff setting. Hence, it is vital for the success of any reforms program to review the performance of existing utilities in terms of current level of operations and standard of services, the condition and serviceability of assets, the human resources, and the financial performances etc. Based on the productivity and efficiency analysis, benchmarks can be set, and targets for improvement of utilities may be identified, thereby helping the utility managers and the policy makers to develop strategic plans for efficiency improvements and for optimal allocation of resources in the sector.

The work is topical and comes at a crucial time when the Indian government has initiated measures that promise to revamp the sector. The dissertation is a pioneer study on evaluation of performances in the Indian Electricity Distribution Divisions (EDDs), as so far no known study has attempted such comprehensive sector measurement by employing advanced benchmarking technique such as the Data envelopment Analysis (DEA) employed in the present analysis.

Such a study can be regarded useful from the following viewpoint:

- The study provides the efficiency scores of the Electric Distribution Divisions (EDDs) of Uttarakhand so that they can rank themselves, identify their shortcomings, can set targets, and try to achieve these targets.
- The model can be extended for use by regulatory commissions for tariff setting, and as a tool for developing a monitoring system.

- The analysis can have future application in the form of X-factor calculations under the incentive based regulation.
- The results can be used for preferential funds allotment with division wise targets under various government schemes such as the allocation of APDRP fund of the government of India.
- Such a study can help to create awareness and competition amongst the EDDs, for sustained improvements in the distribution sector.

The work will be particularly useful to various stakeholders in the power industry including the government and the public bodies, regulatory authorities, funding institutions and the consumers. The results of the study can provide a common basis for informed policy debate and decisions, and can facilitate in initiating a dialogue between stakeholders.

1.7 OBJECTIVE AND SCOPE OF THE STUDY

The objective of the present work is to evolve a framework that may be applied for evaluating efficiencies of the Indian electric utilities in context of post Electricity Act 2003 periods. The work also aims to discuss some of the related policy issues for the sector in the context of its sustainability.

More specifically, the scope of the work comprises the following:

- To review the Indian electricity sector, and the related reforms program.
- To carry out the impact assessment of the Electricity Act 2003.
- To study the distribution sector critically and identify the major inefficiencies prevalent in the sector.
- To establish the need for evolving performance appraisals of the power supply utilities in India in the current context.
- To measure efficiencies and productivities of Electric Distribution Utilities in the reform and restructuring era and to examine results in the policy context to suggest possible sector improvement.

The work incorporates choice of a suitable methodology for efficiency measurement and benchmarking including the estimation of best practice frontier depending on the nature of the data collected. The data analysis identifies inefficient units, quantum of the inefficiencies and also the efficient levels of input usage.

1.8 ORGANIZATION OF THE THESIS

The organization and important developments of this thesis are given in following sequence:

Chapter 1, the current chapter, introduces the major issues involved in power system restructuring and their consequential impact on the power sector performance. It analyses the inefficiencies prevalent in the sector that motivated the present research, and further summarizes the contribution of the present thesis.

Chapter 2 presents a literature review of DEA application to performance evaluation in Generation, transmission and distribution of power sector. It addressed international benchmarking studies and Malmquist productivity analysis applied to power sector. It also provides DEA extension tool applied for efficiency assessment of the power sector.

Chapter 3 presents a critical review of the reform program initiated by the government of India. This chapter evaluates the Indian power sector, explores its evaluation and structure, and examines the electricity reforms in India. This chapter lays special emphasis on the Electricity Act 2003 that has unleashed major sector revamping, and promises to bring in a paradigm shift in the Indian electricity reform program.

Chapter 4 analyses and discusses the performance of Electricity Distribution Divisions (EDDs) of Uttarakhand power corporation limited, Uttarakhand India. The performances have been evaluated using DEA and Malmquist productivity indices.

Chapter 5 presents a micro level study of the distribution division to identify the type of inefficiency prevalent in EDDs. It also provides improvement directions to inefficient divisions through slack analysis. Based on the DEA results, reorganization is investigated for the divisions to enhance the efficiency of the system.

Chapter 6 introduces cross efficiency measures in DEA to differentiate the true overall efficient divisions from false positive divisions. Benchmark share-measure is calculated to trace out the role of each efficient division played in benchmarking inefficient divisions.

Finally, Chapter 7 gives the results and conclusions of the work performed during this study. The scope of future research in the area of restructuring, and efficiency assessment of power utilities has also been explored.

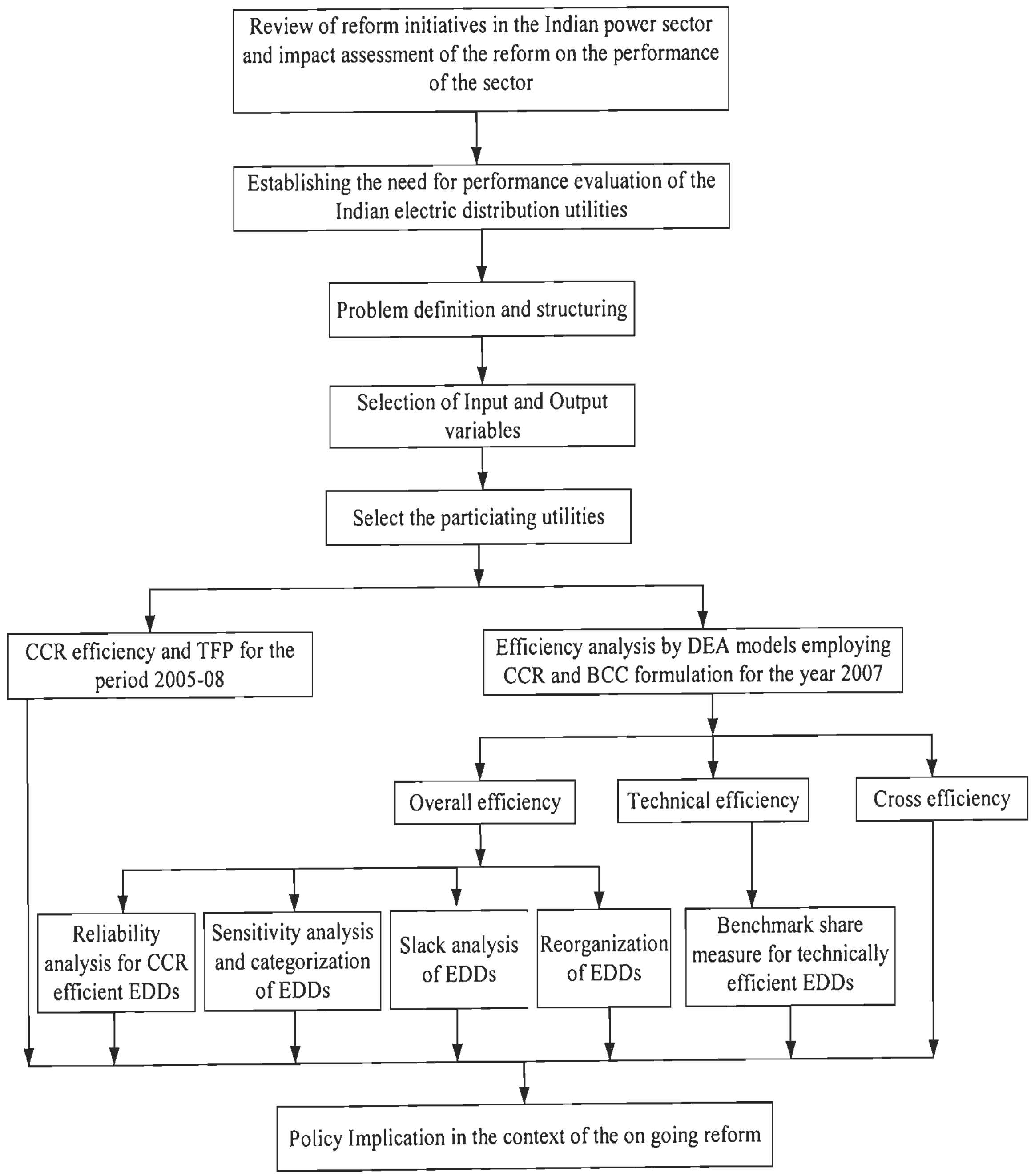


Fig. 1.2: Flow chart for the research work

Chapter-2
LITERATURE REVIEW

2.1 INTRODUCTION

Since the late 1980s, a wave of reform has transformed the institutional framework, organization, and operating environment of the infrastructure industries, including that of the electricity sector, in many developed and developing countries. In addition, number of other countries are either implementing or evaluating some form of power sector reform. Although the structure of power sectors and the approaches to reform vary across the countries, the main objective is to improve the efficiency of the sector.

The main features of many power sector reforms is the market-orientation of their approaches to achieve the efficiency objective by using the discipline of the product and capital markets to achieve allocative and internal efficiency through competition, privatization and price mechanism [70]. These reforms generally involve introduction of competition into electricity generation, design of organized power markets, transmission, distribution, and supply (or retailing) activities. Other power sector reforms have also involved ownership transfers and privatization of existing assets [122].

2.2 BENCHMARKING METHODS AND TECHNIQUES

Since the 1973/1974 world oil crisis, energy researcher's enthusiasm in formulating and applying analytical/modeling techniques in energy studies has increased tremendously [38]. The enthusiasm was further enhanced by the world-wide awareness and concern on environment issues in the 1980s. A number of modeling techniques have as a result been developed and employed to address complex energy issues. For example, Jebaraj and Iniyan [146] reviewed different types of models for energy planning management. The application of decision analysis in energy and environmental studies have been reviewed by Huang *et al.* [64] and updated by Zhou *et al.* [125].

The frontier-based benchmarking methods identify or estimate the efficient performance frontier from best practice in an industry or a sample of firms. The efficient frontier is the benchmark against which the relative performance of firms is measured. Among the wide spectrum of energy modeling techniques, DEA, a relatively new non-parametric approach to efficiency evaluation, has attracted much attention. Along with the wave of deregulation in energy sector since the late 1980s, DEA has been accepted as a major frontier technique for benchmarking energy sectors in many countries, particularly in electricity industry [94, 156]. Built upon the earlier work of Farrel [100], DEA is a well established methodology to evaluate the relative efficiencies of a set of comparable entities by some specific mathematical programming models. These entities, often called Decision Making Units (DMUs), perform the same function by transforming multiple inputs into multiple outputs. A main advantage of DEA is that it does not require any prior assumptions on the underlying functional relationship between inputs and outputs [92]. It is therefore non-parametric approach. DEA is a data-driven frontier analysis technique that floats a piecewise linear surface to rest on top of the empirical observations [177].

Since the work by Charnes *et al.* [3, 4], DEA has rapidly grown into an exciting and fruitful field, in which operations research and management science (OR/MS) researchers, economists, and experts from various application areas have played their respective roles [45, 46]. For DEA beginners, Ramanathan [141] provide an excellent introductory material. The more comprehensive DEA expositions can be found in the publication by Cooper *et al.* [178]. This chapter endeavors to explore and acknowledge the previous works in the area of efficiency measurements through DEA in the electricity sector.

2.3 GENERATION

Fare *et al.* [137] applied DEA model to evaluate the relative efficiency of the electric utilities regulated by Illinois Commerce Commission (ICC). Athanassopoulos *et al.* [5] used Data Envelopment Scenario Analysis (DESA) to set the targets in electricity generating plants. Their study gives different performances in different policies taken by the management. Another application of DEA was conducted by Golany *et al.* [19] to measure the efficiency of power plants in Israel. Olatubi and Dismukes [176], in their papers attempted to measure cost efficiency opportunities for coal-fired electric generation facilities. Non-parametric measurement techniques were applied for plant-specific information. Paper approach also partitioned cost efficiency into its component parts and considered the influence that fuel type, technology, vintage and size has on operating efficiency. Results showed considerable opportunities for cost reduction in the industry that could result in price reductions to electricity consumers. Lam and Shui [123], applied the DEA approach to measure the technical efficiency of China's thermal power generation based on cross-sectional data for 1995 and 1996. Results showed that municipalities and provinces along the eastern coast of China and those with rich supplies of coal achieved the highest levels of technical efficiency. Sarica and Or [84] analyzed and compared the performance of electricity generation plants in Turkey through application of DEA. They also investigated relationship between efficiency scores and various input/output factors. Zhou et al. [126] presented a literature survey on the application of DEA to Energy and Environmental (E&E) studies. They also discussed issues related to the selection of DEA models in E&E studies. Jamasb and Pollitt [158] examined the incentive properties and related aspects of the reference firm model-Network performance assessment model (NPAM)-was used in Sweden and compared this with frontier based benchmarking methods. They identified number of differences between two approaches that are not readily apparent and discussed their ramifications for the regulatory objectives and process. Sueyoshi *et al.* [161] proposed a new DEA approach to evaluate the operational, environmental and both-unified performance of coal-fired power plants that operated under the US Clean Air Act (CAA). They used Range-adjusted Measure (RAM) because it can easily incorporate both desirable and undesirable outputs in the unified analytical structure. Arocena [115] analyzed the degree of economies of vertical integration, diversification and scale in the electricity industry by means of DEA. He estimated the impact that alternative form of unbundling would have on the cost and quality of supply, measured as the number and duration of supply interruption, in a group of Spanish electric utilities.

2.4 TRANSMISSION AND DISTRIBUTION

Prior to 1990, the use of DEA in electricity mainly focused on electricity generation plants, e.g. Fare *et al.* [135, 136, 137]. Since the early 1990s, DEA has gradually become a popular benchmarking tool for studying the efficiency of electricity distribution utilities. The study by Weyman-Jones [152] applied DEA to the regulated electricity distribution industry in England and Wales. He found that only five of the twelve electricity boards were technically efficient, and there was wide divergence in performance amongst them. Targets for improvement of inefficient electricity boards were suggested and implications for the regulatory mechanism were drawn. The author concluded that DEA provides a good comparison of distribution companies operating in a regulated environment. After that, many studies have appeared in the literature and the study scope has also expanded from a single country case to a cross- country case (also called international benchmarking). Hjalmarsson and Veiderpass [86] examined the efficiency of electricity retail distributors in Sweden. In the paper productive efficiency measures were calculated using different versions of the DEA method and also compared different type of ownership and service areas. The result of their study indicated a low level of technical efficiency and a high level of scale efficiency in the rural areas while no significant difference in efficiencies of different type of ownerships or economic organizations were observed. Miliotis [113] evaluated the efficiency of 45 EDDs of Greek Public Power Corporation. The research considered eight factors, including the number of served customers, network length, capacity of installed transformation points, etc. Four different cases with different sets of input and output factors were compared. Bagdadioglu *et al.* [109] used DEA to determine the relative performance of the publicly and privately operated distribution organizations in Turkish electricity market. Pahwa *et al.* [14] performed benchmarking of the electric distribution utilities based on their performances. They used DEA technique to determine relative efficiencies of 50 largest distribution utilities in USA. Jamasb and Pollitt [156] discussed the main benchmarking methods and presented the findings of a survey of the methods in OECD and few other countries. They outlined the main outstanding issues and lessons for best practice implementation of benchmarking for regulation. Lo *et al.* [48] applied DEA to evaluate the relative efficiencies of twenty two electricity distribution districts of the Taiwan Power Company, Taiwan. This study also investigated different reorganization alternatives to increase the efficiency. Resende [106] analyzed relative efficiency measurement and prospects for yardstick competition in Brazilian electricity distribution, while for Latin America a benchmarking study was conducted by Estache *et al.* [7]. Chien *et al.* [21] conducted a DEA study to evaluate the relative efficiencies of 17 service centre of the NAN-TAU electricity distribution districts of Taiwan Power Company. In addition, they also investigated alternatives for reorganizing the service centers via efficiency measurement. Massimo *et al.* [43] analyze the cost structure of Slovenian distribution operators with respect to the cost and scale efficiency of the industry. Azadeh *et al.* [1] presented an integrated Data Envelopment Analysis (DEA)-Stochastic Frontier Analysis (SFA)-

Principal Component Analysis (PCA)-Numerical Taxonomy (NT) algorithm for performance assessment, optimization and policy making of electricity distribution units in Iran. The integrated approach would yield in improved ranking and optimization of electricity distribution systems. Taniguchi and Kaneko [108] examined efficiency changes over the last 15 years of Bangladesh rural electric co-operations using DEA. Then, the critical determinants of the efficiency changes including political indicators are identified with an application of the Tobit model. Huang *et al.* [181] employed the stochastic Meta frontier approach to estimate the cost efficiency of Taiwan's electricity distribution industry. They calculated both short-term and long-term optional scales of electricity distribution firms, lending policy implication for the deregulation of the electricity distribution industry.

2.5 CROSS COUNTRY STUDIES

Pollitt [105] examined the effects of the public versus private ownership on performance through an international comparison of electricity generation, transmission, and distribution utilities using DEA, COLS, and SFA models. The study did not find strong evidences that performance is affected by ownership. The results also suggested that RECs in the UK were, prior to privatization, not less efficient than US distribution utilities.

Benchmarking studies generally target in one or more countries. Lawrence *et al.* [33] reported a notable exception in the form of international multi-industry Economics. The project was carried out between 1991 and 1996 and examined the relative efficiency of eight Australian infrastructure industries, including the electricity sector, using price, service equality, labor productivity, and capital productivity as indicators. The size of the sample for the indicators varies from 19 and 41. On the whole, the Australian electricity sector appeared to be closing some aspects of performance gap with international comparators.

IPART [61] reported a cross-country benchmarking study sponsored by the New South Wales (NSW), Australia regulator. The study examined relative efficiency of 6 distribution utilities in NSW using an international sample of 219 distribution utilities from Australia, England and Wales, New Zealand, and US. The study estimated that the NSW utilities were, after adjustment of efficiency scores for the effect of environmental factors, between 13% and 41% less efficient than frontier firms. Also, Whiteman [76] applied DEA and SFA methods to 7 Australian and an international sample of 32 electricity supply utilities. The study found that X-inefficiency in the Australian utilities may have declined.

Pardina and Rossi [107] examined performance development of 36 American distribution utilities between 1994 and 1997 using SFA. The study did not found evidences of catching up among the utilities sector during the period. Their findings also suggested better performance among the utilities operating in countries which have implemented power sector reforms. The study also found that utilities operating in countries with a reformed power sector have increased their capital share, whilst those in countries without such reforms have increased their labor share. In addition, Whiteman [75], Yunos and Hawdon [63] and Meibodi [11] applied DEA to measure relative efficiency of the electricity systems of developing countries and find considerable efficiency variations. Wang [28] calculated productivity changes in 23 OECD countries between 1980 and 1990. Jamasb and Pollitt [157] presented an international benchmarking study of 63 regional electricity distribution utilities in six European countries that aims to illustrate the methodological and data issued encounter in the use of international benchmarking for utility regulation. This rather unique study was significant from the view point of international benchmarking, and demonstrated as to how the result can help in setting price control in the context of international experience.

2.6 MALMQUIST PRODUCTIVITY INDEX

In the foregoing the use of DEA is restricted to cross-sectional, i.e. multilateral comparisons among different DMUs at the same point in time. However, in the case of energy sectors, there is generally a great interest in investigating their productivity change over time. The non parametric MPI is such a formal time-series analysis method for conducting performance comparisons among different DMUs over time by solving some DEA-type model [37, 134, 147]. MPI has been applied in the literature extensively to industries and whole economies.

The first attempt to derive productivity change measurement was undertaken by Kendrick [71], which was further refined in subsequent works [72, 73, 74]. The next important use of this approach was by Barzel [180]. Barzel looked at the annual productivity changes from 1929 to 1955 for the privately owned power industry in

America. Over the following year a number of studies were reported for the American sector. In 1980s attention was shifted to other countries as the reform of the electricity sector began around the world. For example, Bishop and Thomson [96] calculated the Total Factor Productivity (TFP) of British industries during 1970-1990, while Lawrence *et al.* [34] and Industries Assistance Commission (1989) reported findings from the Australian sector. During 1980s a number of studies concentrated on components other than electricity generation. Forsund and Kittelsen [47] examined Norwegian electricity distribution utilities in terms of Malmquist index. This study determined total factor productivity, shifts in the frontier technology and change in efficiency from 1983 to 1989. Most of the Norwegian utilities tended to have a positive productivity growth of about 2% annually, and frontier technology shifts played a vital role. Burns *et al.* [116] conducted a dynamic benchmarking analysis for 12 regional electricity distribution utilities in Great Britain for the period 1990-1999 using a DEA approach, and also investigated efficiency changes over time. Significantly, the study concluded that a panel analysis delivers more robust results than studies based on cross sectional data. Other examples of panel-data approaches include analysis of Swedish electricity retail distributors [86], productivity study for Norwegian electricity utilities [47].

Hirschhausen and Andreas [27] provided a productivity analysis of German electricity distribution companies using DEA. The study addressed both traditional issues such as the role of scale effects and optimal utility size in electricity sector benchmarking, as well as new evidence specific to Germany. Giannakis *et al.* [31] presented a quality-incorporated benchmarking study of the electricity distribution utilities in the UK between 1991-92 and 1998-99. They calculated technical efficiency of the utilities using DEA and productivity change over time using Malmquist indices. The Australian electricity sector was studied by Abbott [95], who evaluated the improvements in the productivity and efficiency performances after sector reforms. Wang *et al.* [62] performed an empirical efficiency analysis using DEA to analyze the efficiency and performance of the Hong Kong electric supply utilities and its effects on prices under the price-cap performance based regulation (PBR) model. They also computed total factor productivity with the Malmquist productivity index. Results of case studies supported the use of the approach to account for the relation of the X-factor and the PBR model on the two power utilities in Hong Kong's electricity supply industry. Pombo and Taborda [25] assessed evolution in performance, efficiency and productivity of Colombia's power distribution utilities before and after the 1994 regulatory reform using DEA and Malmquist productivity index and the results of the analysis suggested a positive effect of reform policy.

Comparative productivity studies across developed nations have also been reported in the literature. For example, Edvardsen and Forsund [30] studied large distribution utilities from Denmark, Finland, Norway, Sweden, and Netherlands for the year 1997 by assuming a common production frontier for all countries. New indices describing cross-country connections at the level of individual peers and their inefficient units as well as between countries were developed using Malmquist productivity indices. Across continents, Hattori *et al.* [153] made use of DEA and SFA approaches to analyze productivity growth in a sample of Japanese and UK electricity distribution businesses over the period 1986-1998. Estache *et al.* [6] calculated the change in TFP of the largest operators in Africa's electricity firms. Reyes and Tovar [140] analyzed the evolution of productivity of the electricity distribution companies in Peru, to assess whether reforms have improved the efficiency in the sector they also identified potential sources of productivity changes, based on market restructuring the electricity sector and changes in property. Ramos-Real *et al.* [40] estimated changes in the productivity of the Brazilian electricity distribution sector using DEA on a panel of 18 firms from 1998 to 2005. They decomposed the productivity change of these distribution firms in terms of technical efficiency, scale-efficiency and technological progress. They revealed that the incentives generated in the reform process do not seem to have led the firms to behave in a more efficient manner. Goto and Sueyoshi [99] examined the cost structure of Japanese electricity distribution through a multi-product translog cost function from 1983 to 2003. Using the estimated cost function, they calculated several economic measures such as productivity growth, technical change and economies of scale and scope.

2.7 EXTENSIONS TO BASIC DEA MODELS

As was described by Ramanathan [141] and Cooper *et al.* [178], large number extensions to basic DEA models have appeared in the literature. In traditional DEA model including the CCR, the inputs and outputs are assumed to be strongly or free disposable. In a fossil- fuel-fired electricity generation plant, the generation of electricity is always accompanied by the production of undesirable outputs such as sulfur dioxide. In such cases, the reduction of undesirable outputs would likely be costly. Many methods have been proposed to incorporate undesirable outputs into DEA model [56]. Generally, these methods can be divided into two groups. One is based on data translation and the utilization of traditional DEA models, e.g. [29, 89]. The other used the original data but is based on the concept of weak disposability reference technology as proposed by Fare *et al.* [132].

Sueyoshi and Goto [162] used a new slack-adjusted data envelopment analysis (SA-DEA) model which explicitly incorporates an influence slacks into its efficiency measurement for Japanese electric power generation industry in 1984-1993. In order to improve DEA discriminating power, Sexton *et al.* [160] constructed a cross efficiency matrix which contains not only a DMUs usual DEA efficiency, called self-rated efficiency, but also DMUs cross efficiency rated by each of other DMUs within the group. These efficiencies are then averaged for the DMU and the resulting value becomes a new measure of efficiency for the DMU. The cross-efficiency matrix has since been a widely used technique, particularly when number of DMUs is relatively small and discrimination among DMUs is a major concern. The application and extensions of the cross efficiency matrix can be found, for example in Doyle and Green [66], Shang and Sueyoshi [69] and Green *et al.* [138]. Chen [166] has compared technical efficiency and cross efficiency scores of the electricity distribution sector in Taiwan. He employed the cross-efficiency evaluation to identify the overall efficient and 'false standard' efficient electricity distribution districts. A Multiple Criteria Data Envelopment Analysis (MCDEA) can be used to improve discriminating power of DEA methods and also effectively yield more reasonable input and output weights without a priori information about the weights [179].

However, application of DEA for performance evaluation of electric utilities has been very limited in India. For example, Chitkara [112] has carried out first study applicable to Indian power generating plants to evaluate the operating inefficiencies of generating units. By using DEA he derived best practice frontier, which could serve as a benchmark for efficiency improvement. Most of the preceding DEA studies had focused on just measurement of the inefficiencies, but Chitkara also provided the causes of those inefficiencies of generating units. Thakur *et al.* [164] carried out a comparative study of 26 State Owned Electric Utilities (SOEUs), which are mainly responsible for the generation, transmission and distribution of electricity in India, using DEA. Impact of scale on the efficiency scores was also evaluated and results indicated that the performance of several SOEUs was sub-optimal, suggesting the potential for cost reductions.

2.8 CONCLUDING REMARKS

DEA is becoming more and more popular in benchmarking of electricity utilities. Benchmarking methods have proved to be an important decision-aid tool in utility regulation and countries have also adopted it for incentive regulation. In addition, there has been a growing interest on the use of nonparametric MPI in power sector in recent years. The survey reveals that the effects of reforms in a number of developed economies are now being widely documented through application of benchmarking techniques, yet, apart from a few case studies, the experiences of developing countries including India remain much less researched. However, to date no micro level research has been reported on EDDs for Indian power sector. A micro level intra-state analysis based on DEA will reveal finer elements causing inefficiencies and will highlight the reasons for inefficiencies. The subsequent chapters of this dissertation work intend to fill this gap in terms of pioneering effort to quantify performance of Indian electric distribution utilities.

Chapter-3

THE INDIAN ELECTRICITY SECTOR: ORGANIZATIONAL STRUCTURE AND CRITICAL REVIEW OF REFORMS

3.1 INTRODUCTION

Since 1947 after independence, India has taken rapid strides in the power sector both in terms of enhancing power generation and in making the power available across widely spread geographical boundaries with an acceptable degree of reliability and quality [127]. The installed generation capacity in the power utility sector has been increased from a mere 1,362 MW in 1947 to 1, 64,835.80 MW as on 31st October 2010 [104]. The power transmission & distribution network has also grown substantially. The per capita consumption of electricity in the country has increased from 15 kWh in 1950 to 704 kWh in 2010 and it is expected that it would be about 1000 kWh per annum at the end of XIth Five Year Plan(FYP) i.e. in 2012 [104]. However, this is fairly low in comparison to that of some of the developed and emerging nations such as US (approx. 15,000 kWh) and China (approx. 1,800 kWh). The world average stands at 2,300kWh.

At the time of Independence, only about 1500 villages of the country had access to electricity and about 6430 pump sets were energized. The scenario has changed significantly over years. Till July 2010, 60% of the pump sets potential in the country has been exploited through energized pump sets to augment irrigation facilities and increase agricultural productivity. It has been possible to extend electricity to about 500 thousand villages by the end of March 2010, thereby resulting in electrification of about 84% villages [54]. As per rough estimates 18,000 un-electrified villages are located in remote and difficult areas and it is not possible to extend power supply to these villages through the existing power grid. Electrification of these villages therefore is proposed to be achieved through various sources of distributed generation including non-convention sources of energy. Installation of distributed generation will ensure higher reliability and enhanced power quality for sensitive loads [144].

Electricity is provided to the entire country mainly through the State Electricity Boards (SEBs). Historically, the SEBs has not adequately been able to scale generation to the demanded level with corresponding expansion in transmission and distribution networks. This fact was comprehended in mid seventies when it was felt that the central government should come forward to take up generation and transmission projects to augment the efforts of states for improving the power supply scenario. Agencies like National Thermal Power Corporation (NTPC), National Hydro Power Corporation (NHPC) were subsequently set up in a phased manner. The supplementary efforts by central sector utilities in adding substantial generation and new transmission projects have helped in improving the overall power scenario in the country. During the early nineties, generation was opened to private sector with a view to mobilize additional resources. Despite these efforts, the condition of power supply industry has not been up to the mark [164] due to compounding effects of numerous attributes that owe their existence to the organizational structure of the power sector, and especially to the maladies afflicting distribution sector.

This chapter evaluates the Indian power sector, explores its evolution and structure, and examines the electricity reforms in India with special emphasis on the Electricity Act, 2003 that has unleashed major sector revamping with reference to Uttarakhand electric utility.

3.2 BACKGROUND OF THE ELECTRICITY REFORM IN INDIA

Basic and radical restructuring of the power sector had become imperative to improve the consumer services and also even for the sustenance of the power sector [148]. India took the first steps towards power sector reform in 1991 by allowing entry of independent power producers (IPPs). Fig. 3.1 gives the summary of evaluation of legal framework in the Indian power sector from time to time. Since then, and despite experimenting with a number of alternative reform paths and the adaptation of a new legal framework in 2003 to facilitate major structural changes, the country has made little progress in achieving the stated reform goals. Meanwhile, the electricity sector continues to perform poorly. Peak capacity shortage and energy deficit continued reaching new heights during the summer of 2009, when power cuts of 3-8 hours were quite common in many parts of the country. The precarious financial condition of industry, exemplified by a rate of return of -18% for the SEBs in 2007-08 remained a serious concern. Investment in power generation capacity has fallen short of expectation. For example, there were significant capacity slippages from five year plan targets both in IXth and Xth Plans (to the extent of 53% and 25% respectively) [58]. Despite the facts reforms have achieved quite a significant mile stones with respect to the following aspects:

- Separation of policy, regulatory and operational responsibility including setting up of independent regulatory commissions at the central and state level.
- Increased commercial autonomy to distribution companies.
- Unbundling for focused benchmarking across entities and introducing transparent administration.
- Institutional reform and capacity building initiatives including development of organizational capabilities.
- Transparent governance of the sector including better subsidy administration and well defined enabling legal, policy, regulatory and commercial frameworks.

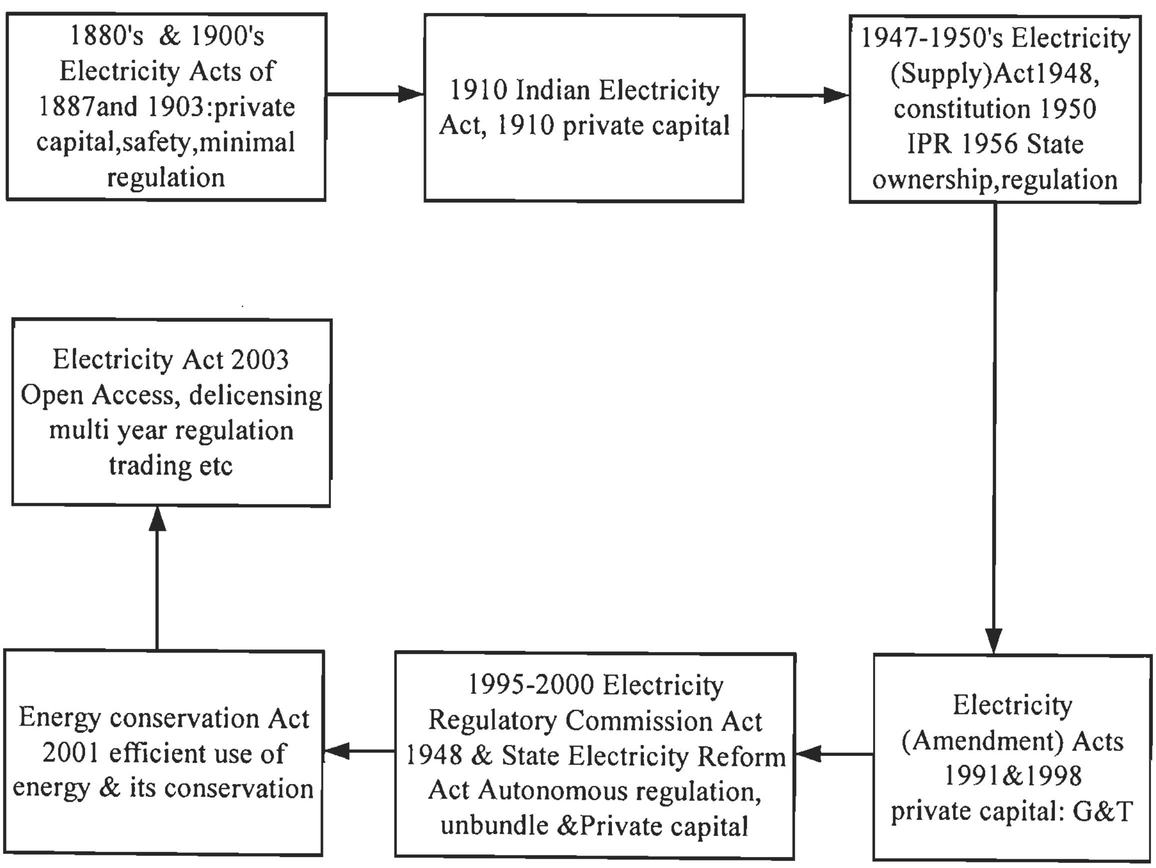


Fig. 3.1: Evolution of legal framework

3.2.1 Major Legislative Initiatives in India

The power sector in India has witnessed four important legislations:

3.2.1.1 The Indian Electricity Act, 1910

- Provided basic framework for electric supply industry in India.
- Growth through private licensees with license provided by state government.
- Provision for license for supply of electricity in a specified area.
- Legal framework for laying down of wires and other works.
- Provision for laying down relationship between licensee and consumer.

3.2.1.2 The Electricity (Supply) Act, 1948

- Mandated creation of SEBs.
- Need for the state to step in (through SEBs) to extend electrification (so far limited to urban centers) all across the country.

3.2.1.3 The Electricity Regulatory Commission Act, 1998

- Provision for setting up of Central Electricity Regulatory Commission (CERC)/State Electricity Regulatory Commission (SERC) with powers to determine tariffs.
- Constitution of SERC optional for states.
- Distancing of government from tariff setting process.
- Rational for change in legislative framework.

3.2.1.4 The Electricity Act, 2003

Recognizing the need for a paradigm shift in the reform process rather than the piecemeal approach being followed in number of states, a comprehensive Electricity Bill was drafted in 2000 following wide consultative process. After a number of amendments, the bill finally sailed through the legislative process and was enacted on 10 June 2003. It replaces the three existing legislations governing the power sector, namely Indian Electricity Act, 1910, The Electricity (Supply) Act, 1948 and The Electricity Regulatory Commissions Act, 1998. Apart from consolidating such laws relating to generation, transmission, distribution and use of electricity, the main provision for Act are [102]:

- De-licensing of thermal generation and captive generation.

- Provision for license-free generation and distribution in rural areas and provision for management of rural distribution by Panchayats, Corporative Societies, non-government organizations, franchises, etc.
- Non-discriminatory open access in transmission.
- Multiple licensing in distribution.
- Open access in distribution to be introduced in phases. Provision for cross-subsidy surcharges on direct sale to consumers until cross subsidies are gradually phased out.
- Power trading recognized as a distinct activity with ceiling on trading margins to be fixed by the regulatory commissions.
- Provision for payment of subsidies through budget.
- Setting up of an Appellate Tribunal to hear appeals against the decisions of the CERC and SERCs.
- Mandatory metering of all electricity supply.
- Adoption of multi-year tariff principles.

The act provides a conducive environment for potential investors in the power sector by removing administrative hurdles, apart from some control over hydro electric projects due to a multitude of issues related to water utilization, flood control, etc. The act introduces a phase shift in the reform process, providing the necessary impetus to the sagging momentum for distribution reforms in the country.

3.3 INDIAN INSTITUTIONAL ORGANIZATION: AN OVERVIEW

The power sector in India has been regulated and owned for many years by various government agencies and organizations. The subject of electricity is covered under the concurrent list in the constitution of India, implying that both the central and state governments have the power to make policies for the sector. While generation and transmission has participation from both the central and state governments, distribution segment fall within the purview of respective state governments. Reforms at the central level that span generation and transmission related issues covering more than one state were initiated in 1998, through enactment of the Electricity Regulatory Commissions Act, which provided for the setting up of the CERC and SERCs. The main functions of CERC are regulating tariffs of generating companies, owned or controlled by the Government of India and other generating company catering to more than one state, and also tariffs for the inter-state transmission of electricity. Apart from this, two significant steps taken by CERC include introduction of Availability Based Tariffs (ABT), Indian Electricity Grid Code. The overall institutional structure of the Indian power industry, presently in existence is shown in Fig. 3.2. The Power Finance Corporation (PFC) was incorporated in 1986 to function as the prime financial institution dedicated to the growth and the overall development of the Indian power sector. PFC provides funds to SOEUs and private utilities. The Power Grid Corporation of India Limited (PGCIL) was established in 1989 to operate regional and national power grids and facilitates the power transmission reliability, security and economy. The Power Trading Corporation (PTC) of India limited was constituted in 1999 to purchase and sale electric power, to plan and promote an effective and reliable power trading and distribution system, with majority equity participation by the PGCIL, NTPC, PFC, and other financial institutions. The National Power Training Institutes (NPTI) acts as the national apex body for the human resources development of the power sector in India, while the Energy Management Center (EMC) was set up in 1989 to strengthen energy management capabilities in the country through workshops, training, seminars, multimedia, awareness campaign etc.

<table>
<tr><th>Functions</th><th colspan="2">Centere</th><th colspan="3">State</th></tr>
<tr><td>Policy</td><td colspan="2">Ministry of Power</td><td colspan="3">State Government</td></tr>
<tr><td>Plan</td><td colspan="2">CEA</td><td colspan="3"></td></tr>
<tr><td>Regulation</td><td>CERC</td><td>CAC</td><td colspan="2">SERC</td><td>SAC</td></tr>
<tr><td>Transmission</td><td colspan="2">CGS, Mega Power Plants</td><td colspan="3">GENCOS</td></tr>
<tr><td>System Operations</td><td>CTU</td><td>Transmission Licensee</td><td>STC</td><td>Transmission Licensee</td><td rowspan="3">Private Generation & Distribution in Some Cities</td></tr>
<tr><td>Distribution</td><td>NLDC</td><td>RLDC</td><td colspan="2">SLDC</td></tr>
<tr><td>Trading</td><td colspan="2">Trading Licensee</td><td colspan="2">SDC/Distribution Licensee</td></tr>
<tr><td>Appeal</td><td colspan="2">Appellate Tribunal</td><td colspan="3">Trading Licensee</td></tr>
</table>

Fig 3.2: Indian power industry structure

3.4 STATUS OF REFORM IN DIFFERENT STATES

The restructuring program in the form of complete privatization of SEBs started with the state of Orissa in 1993. Orissa then became the first state not only in India, but also in the entire south Asia, to implement a comprehensive power sector reforms program. This restructuring program had the active involvement of multilateral lending agencies like the World Bank, Department for International Development, Government of UK (DFID) and the Asian Development Bank, and several leading management consultants [129]. The experience of Orissa has been important to other states in India, which were restructuring their SEBs more or less on the lines of the Orissa experiment. In July 2002, Delhi became yet another state that opted for privatization of the Delhi Vidyut Board. The Government in the of Delhi was able to sell majority stakes in three distribution utilities covering the entire metropolitan area, even though the total operational and commercial losses were close to 50%. In Orissa and Delhi power distribution was entirely privatized. While Delhi was a success story and Orissa was a failure. The regulator in Orissa has not been fair in deciding the tariffs. There has been a problem both from the government as well as the private players' side. Status of reform in the major Indian states is presented in Table 3.1.

27 states in India have either constituted or notified their regulatory commission and 22 have tariff orders in the direction of rationalizing the tariffs. Now the states are moving towards multi-year tariffs, time of day metering and intra state availability based tariff. 15 SEBs/Electricity Departments have been unbundled and corporatized. Orissa, Haryana, Uttar Pradesh, Andhra Pradesh, Karnataka, Rajasthan, Madhya Pradesh and West Bengal were the first Indian states that had unbundled their activities and have separate generation, distribution and transmission companies. These states have commercialized their activities but they are still under the government control; effective privatization has been introduced only in Orissa and Delhi states. A close look at the internet sites of reforming sites like Orissa, Andhra Pradesh, Haryana, and Delhi reveals that financial performance of unbundled utilities have improved to a certain extent. These states have invariably taken up the installation of meters in a big way with the financial assistance from World Bank and PFC, and these measures led to an improved revenue collection [12]. At the national level 98% feeders and 88% consumers have been metered so far. 100% feeders metering have achieved in 20 states. With the introduction of Electricity Act, 2003, it is now mandatory for all states to unbundle their services in order to bring about increasing accountability in operations so that efficiencies can improve.

Table 3.1: Status of reform in major Indian States

S. No.	State	SERC			Unbundling / Corporatization		Distribution Reform	
		Constitution year	Operationalisation	Issuing Tariff – Order	Unbundling / Corporatization Implementation	Privatization of Distribution	100% Metering-11 kV Feeder Metering	100% Metering – Consumer Metering
1	Andhra Pradesh	1999	✓	✓	1G, 1T, 4D, 9RC	✓	✓	✓
2	Assam	2001	✓	✓	1G, 1T, 3D	✓	✓	✓
3	Bihar	2005	✓	✓	1SEB	✓	✓	✓
4	Chhattisgarh	2004	✓	✓	1SEB	✓	✓	✓
5	Delhi	1999	✓	✓	1G, 1T, 3D	✓	✓	✓
6	Gujarat	1998	✓	✓	1G, 1T, 6D	✓	✓	✓
7	Haryana	1998	✓	✓	1G, 1T, 2D	✓	✓	✓
8	Himachal Pradesh	2001	✓	✓	1SEB	✓	✓	✓
9	Jharkhand	2003	✓	✓	1SEB	✓	✓	✓
10	Karnataka	2003	✓	✓	1G, 1T, 4D, 1RC	✓	✓	✓
11	Kerala	2002	✓	✓	1SEB	✓	✓	✓
12	Meghalaya	2004	✓	✓	1SEB	✓	✓	✓
13	Maharashtra	1999	✓	✓	1G, 2T, 2D, 2GTD, 1RC	✓	✓	✓
14	Madhya Pradesh	2001	✓	✓	1G, 1T, 3D	✓	✓	✓
15	Orissa	1995	✓	✓	1G, 1T, 4D	✓	✓	✓
16	Punjab	1999	✓	✓	1SEB	✓	✓	✓
17	Rajasthan	2000	✓	✓	1G, 1T, 3D	✓	✓	✓
18	Tamil Nadu	1999	✓	✓	1SEB	✓	✓	✓
19	Uttar Pradesh	2000	✓	✓	2G, 1T, 6D	✓	✓	✓
20	Uttarakhand	2002	✓	✓	1G, 1T, 1D	✓	✓	✓
21	West Bengal	1999	✓	✓	6G, 1T, 1D	✓	✓	✓

3.5 REVIEW OF PERFORMANCE OF THE INDIAN ELECTRICITY SECTOR

Electricity demand in India has increased significantly over the past two decades owing to the rapid economic growth in the post liberalization era. High energy shortage and peak deficit are by and large a common phenomenon in all the states. This can be attributed to operational inefficiency, non-rationality at all phases of trading of energy viz. tariff setting, metering, billing, revenue etc. and inadequate resources for capacity addition [36]. Fig. 3.3 displays the annual capacity addition during 1997-98 to 2008-09. The generation expansion programs during past decade suffered substantial slippage from targets. Capacity addition as a percentage of targets during the VIIIth, IXth and Xth five year plans of 54%, 47% and 75% respectively. However, the shortfall in the Xth plan has been partly offset by improved plant performance and reduction of T&D losses [58].

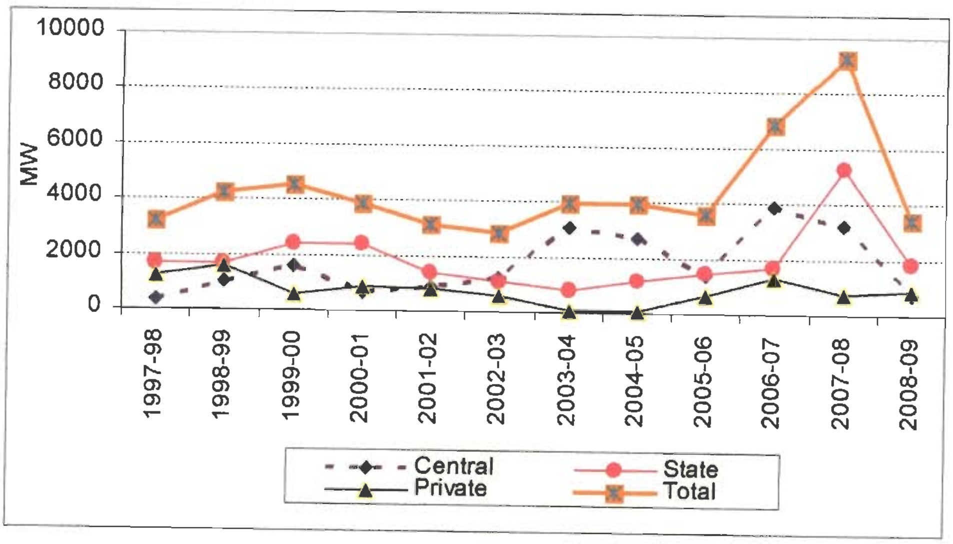


Fig. 3.3: Addition of installed generation capacity
(Source: GoI, 2006, MoP, 2008, 2009)

In order to meet the growing demand in the coming years, during the XIth plan, another 62475 MW of generation capacity will have to be added. As per the estimation of the Central Electricity Authority (CEA), this will have to include 13500 MW from the private sector. Capacity addition of such a magnitude will call for an additional investment of approximately ` 5000000 Million, to be sourced from both the public and private sector [58].

In the year 2008-09, the overall Plant Load Factor (PLF) of power station was 77.2% with the 84.3% central owned stations, 71.2% state owned stations and 91% private owned thermal stations. Plant load factors of thermal power stations have reflected the growth of only 6% from the 1997-98 to 2008-09. Fig. 3.4 represents PLF of thermal stations from the period 1997-98 to 2008-09. Total increase in PLF is mainly contributed by private & central owned thermal stations and the state owned thermal stations still delivering unsatisfactory performance [104]. Plant availability has merely increased from

77.8% in 1995-96 to 81.78% in 2005-06. Auxiliary consumptions of power plants are still high at about 8.44% for the same year [58].

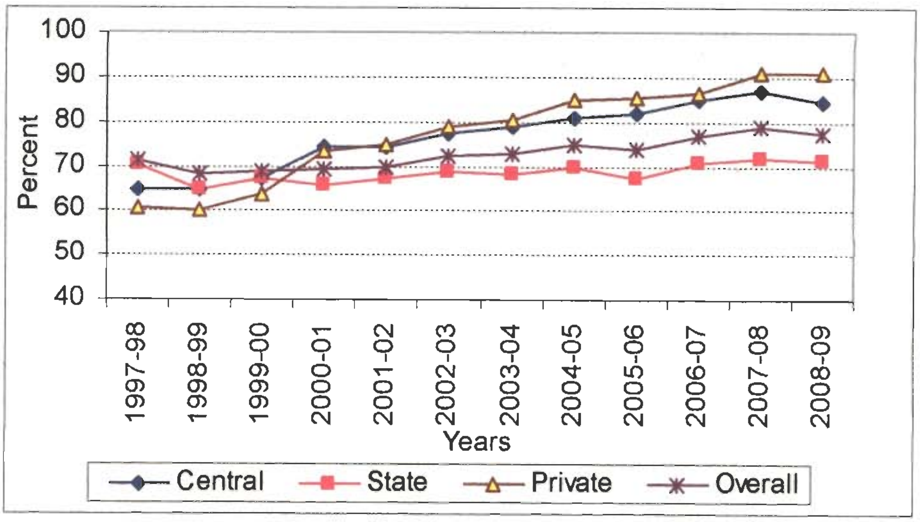


Fig. 3.4: PLF of thermal power stations in India
(Source: Planning Commission, 2002, and MoP, 2009)

Apart from operational inefficiency, reflected in poor energy efficiency and PLF of generating plants of SOEUs, the T&D system poses the most serious burden on the performance of the Indian power sector [16]. The Indian power sector is poorly placed in terms of the level of T&D losses which have swelled to enormous proportions. T&D losses were 24.79% in the year 1997-98 and increased to 28.65% in the year 2006-07 [103, 120]. Even after 8 years of enactment of APDRP, AT&C of state power utilities have not shown much improvement over the past years. AT&C losses still prevail at around more than 30% in SEBs. It showed slight decrease from 38.86% to 33.07% during 2001 to 2009 [50, 104]. AT&C losses for Delhi, Haryana, Maharashtra, Orissa and Rajasthan are between 30-40% and for Madhya Pradesh, Uttar Pradesh, and Uttarakhand it is above 40% [117]. It will not be possible to reduce the technical as well as commercial losses without metering each and every consumer, smaller or bigger, including agriculture [82]. Fig. 3.5 indicates the billing efficiency, collection efficiency and AT&C losses for the period 2001-02 to 2006-07. The billing efficiency at the national level has increased only from 68.37% during 2002-03 to 71.04% during 2006-07. The national average collection efficiency has merely increased from 92.91% during 2002-03 to 94.20% during 2006-07 [50, 104].

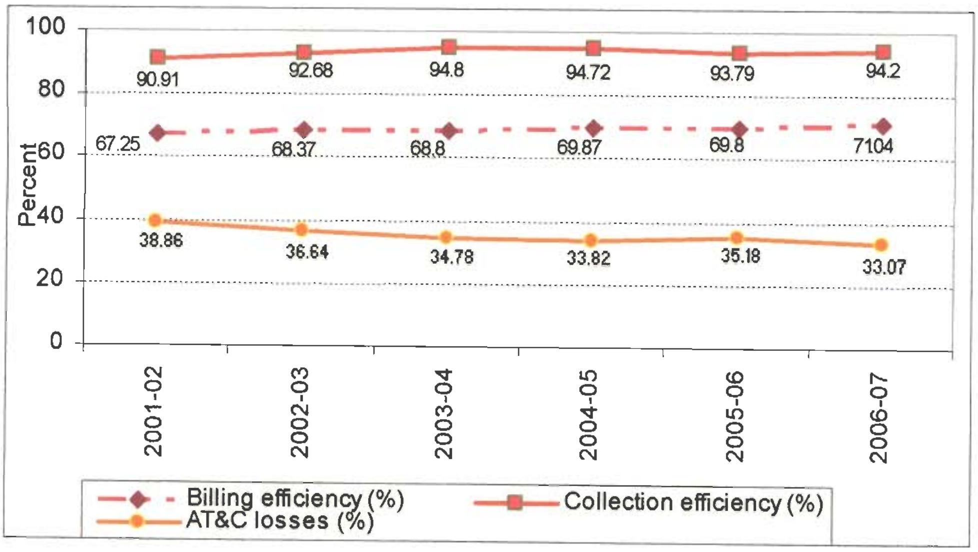


Fig. 3.5: Billing and Collection efficiency and AT&C losses
(Source: GoI, 2006, and MoP, 2009)

Financial performance of SOEUs has also been a major area of concern. The gap between Average Cost of Supply (ACS) and Average Revenue Realized (ARR) was 0.49 ` /kWh in 2006-07. The average unit cost of supply during 2006-07 was ` 2.76/kWh whereas average revenue realized was only ` 2.27/kWh (PFCL, 2008). Commercial losses (without subsidy) were estimated ` 257014 Million in 2007-08 as compared to ` 139630 Million in 1997. Gross subsidy on sale of electricity which was 355390 ` Million in 2005-06 was estimated to rise to ` 431326 Million in 2007-08 [49]. T&D and commercial losses of SEBs for the period 1997 to 2006 are represented in Fig. 3.6.

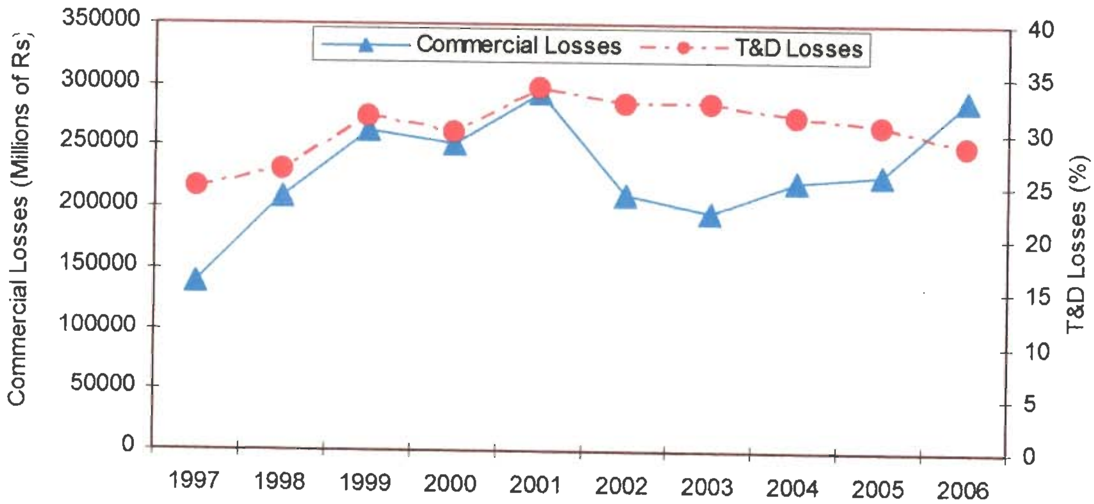


Fig. 3.6: Performance of SEBs
(Source: MoP, 2008, Planning Commission, 2002, and Economic Survey, 2008)

The financial disorders in the SEBs could be attributed to a number of factors, including high T&D losses, overstaffing, large unpaid bills, political interference etc. As a result Rate of the Return (ROR) on the assets employed by the SEBs has been negative. It can be seen from Table 3.2 that ROR of the SEBs have deteriorated and decreased from -12.70% in the year 1991-1992 to -24% in the year 2006-07. ROR recorded -44.10% in year 2001-02, highest of all the year [49, 59, 120].

Table 3.2: Rate of Return (without subsidy) of SEBs

Years	ROR (%)
1991-92	-12.70
1992-93	-12.70
1993-94	-12.30
1994-95	-13.10
1995-96	-16.40
1996-97	-19.60
1997-98	-22.90
1998-99	-34.20
1999-00	-43.10
2000-01	-39.10
2001-02	-44.10
2003-04	-28.32
2004-05	-31.94
2005-06	-19.7
2006-07	-24.0
2007-08 (RE)	-18.0
2008-09 (AP)	-14.3

RE: Revised Estimates; AP: Annual Plan Estimates
(Source: Planning Commission 2002, IMaCS, 2007& GoI, 2008)

It is evident from the above portrayal of financial and technical indicators that a micro level appraisal of the SOEUs is necessary in order to identify the causes underlying inefficiencies and the extent of scope of improvement of these utilities. In this dissertation Uttarakhand state power utility has been selected for performance evaluation study because of convenience in data collection and related enquiries.

3.6 ORGANIZATIONAL STRUCTURE OF UTTARAKHAND STATE ELECTRICITY UTILITY:

The State of Uttaranchal was formed out of Uttar Pradesh and established as a separate state in November 2000. The state of Uttaranchal was renamed "Uttarakhand" in January 2007. The Uttarakhand Electricity Regulatory Commission (UERC) was constituted by Government of Uttarakhand on January 2002 under Electricity Regulatory Commission Act, 1998. UERC promotes competition, efficiency and economy in the power sector and is mandated to regulate tariffs on power generation, transmission and distribution companies within the state, facilitate intra-state transmission of electricity, protect the interests of the consumers and other stakeholders in the state of Uttarakhand and advise the state government. Uttarakhand Power Corporation Limited (UPCL) was incorporated in February 2001. UPCL inherited the Transmission and Distribution in April 2001. The Electricity Act, 2003 mandated the separation of transmission function under power sector reforms. In June 2004, the Power Transmission Corporation of Uttarakhand Limited (PTCUL) was formed to maintain and operate 132 kV and above transmission lines and substations. UPCL is now the distribution utility responsible for the sub-transmission and distribution secondary substations and distribution lines 66 kV and below. Power Generation is undertaken by the state owned company, Uttarakhand Jal Vidyut Nigam Limited (UJVNL) formed in February 2001 [131].

3.6.1 Power Scenario in Uttarakhand

In 2007-08, Uttarakhand power sector faced energy deficit of 2.9% and peak demand deficit of 4.2% which indicates that the availability of energy was unsatisfactory to certain extent [20]. The Uttarakhand power sector is poorly placed in terms of the level of T&D losses which have swelled to enormous proportions in recent years. T&D losses for Electricity Distribution Circles (EDCs) of Uttarakhand during period 2004-2008 are given in Table 3.3.

It can be noted that T&D losses increased from 26.60% to 28.01% during period of analysis. In the year 2005-06, per capita electricity consumption is very low at 654 kWh and needs to be increased to meet the goals of economic and social development. There is very low average consumption in few hilly divisions like Almora, Bageswar and Champawat and also low even in peak winter season December [169].

Even after 8 years of enactment of APDRP, AT&C losses of state power utility have not shown much improvement. AT&C losses still prevail at above 40% in SEB [119]. Electricity distribution divisions (EDDs) like Pithoragarh, Vikasnagar, Haldwani (U), Champawat, Srinagar, Rudraprayag, Roorkee (U), Ramnagar and, Nainital having AT&C losses more than 50% [169]. Still in the state there persist low billing (61.04%) and collection efficiency (93.61%).

Table 3.3: T&D Losses of Electricity distribution circle, Uttarakhand for the period 2004-2008

Electricity distribution circle (EDC)	2004-05	2005-06	2006-07	2007-08	2008-09
EDC (R), Dehradun	27.06%	28.57%	24.47%	26.84%	29.46%
EDC (U), Dehradun	21.00%	20.48%	20.47%	21.92%	21.12%
EDC, Srinagar	21.26%	22.82%	25.44%	28.07%	28.27%
EDC, Roorkee	29.95%	37.21%	36.35%	37.72%	33.18%
EDC, Haldwani	27.99%	25.34%	29.09%	24.47%	26.15%
EDC, Rudrapur	29.09%	28.12%	31.53%	27.44%	24.84%
EDC, Ranikhet	28.29%	26.62%	28.82%	30.97%	29.41%
Uttarakhand	26.60%	28.37%	29.73%	29.65%	28.01%

Looking at the financial performance of Uttarakhand power sector, the gap between ACS and ARR was 15 paisa/kWh in 2004-05 increased to 31 paisa/kWh in 2007-08 which was mainly due to low cash collections as well as increase in operating expenses [118]. ACS of electricity increased from 2.35 `/kWh in 2005-06 to 3.09 `/kWh in 2008-09 [44]. The financial disorders in the state could be attributed to a number of factors, including high T&D losses, overstaffing, large unpaid bills, political interference etc.

3.7 UTTARAKHAND POWER CORPORATION LIMITED

UPCL de-merged from Uttar Pradesh Power Corporation limited (UPPCL) in 2001. The Distribution Company with a 4500 Human Capital workforce is committed to provide high reliability and quality power supply to 1.45 million electricity consumers spread across the 13 Districts in the state of Uttarakhand. Table 3.4 gives the summary of Category wise power consumption from 2005-06 to 2008-09.

Table 3.4: Category-wise consumption (MU) in Uttarakhand from 2005-06 to 2008-09

Categories	2005-06	2006-07	2007-08	2008-09
Domestic	1037	1107	1268	1237
Commercial	593	607	608	749
Agricultural	409	359	300	266
Industrial (LT)	1081	1413	2131	2787
Industrial (HT)	150	155	156	192
Public Lighting	50	41	45	41
Public Water Works	176	196	217	208
Railway	3	7	9	11
Inter-State	96	2	-	-
Total	3593	3886	4736	5493

The organizational structure of UPCL is divided into two zones. Each zone is subdivided into circles (total 7); each circle into divisions (total 30); each division into subdivisions, and subsequently each subdivision into substations (2 zones, 7 circles, 30 divisions till 2009). The company operates and maintains 5 substations of 66/33/11 kV, 260 substations of 33/11 kV with a Sub-Transmission and Distribution system network of 212 km of 66 kV, 3922 km of 33 kV, 33068 km of 11 kV and 48215 km of LT Lines spread across the state periphery.

3.8 ACTION PLAN: INITIATIVES TAKEN FOR EFFICIENCY IMPROVEMENT

The objective of efficiency improvement program is to put together a reliable Distribution System and enhance quality of supply of electricity to the State consumers as well as reducing the overall technical and commercial losses of the corporation. UPCL initiated following Action Plans to achieve the objectives of the reform process [169].

3.8.1 Distribution System Improvement

Following steps have been initiated by UPCL in this direction:

(a) Construction of ring mains in towns to improve reliability in supply.

(b) Converting single phase lines to three phase lines.

(c) Application of High Voltage Distribution System (HVDS) to improve quality of supply.

(d) Strengthening the capacity in the distribution system to be compatible for five years' load growth.

(e) Distribution automation - It is envisaged that all 33 kV and 11 kV feeders shall be automated through a distribution Supply Chain Agent Decision Aid (SCADA) System (in phases) to monitor automatically the operation of the feeders for overloading, tripping and low frequency.

(f) Data logging - This is aimed at compilation of all technical data in respect of the distribution system connected to a 33/11 kV sub-station, including the number and durations of tripping, meter readings of all distribution transformers and feeders connected to the sub-stations.

3.8.2 Loss Reduction Initiatives

These initiatives are aimed at reducing the overall technical and commercial losses in the distribution system and commercial functioning of the Corporation. It involves the following activities:

(a) Complete metering of consumers, including replacement of defective meters.

(b) Total metering of all 11 kV & 33 kV feeders including check meters of all independent/group industrial feeders to facilitate energy accounting.

(c) Distribution Transformers (DT) metering of all DTs in Towns and loss-prone areas.

(d) Consumer indexing & tagging to feeders and DTs to facilitate energy audit at feeder and DT level.

(e) Centralized billing system for high value HT/LT consumers including automatic meter-reading of Time of Day (TOD) meters through Global Systems for Mobile Communications (GSM) and General Packet Radio Service (GPRS) connectivity to ensure zero commercial losses in high value consumers and analysis.

(f) Prepaid metering in all government connections and consumers in towns.

(g) Collection improvement measures through installation of Any Time Payment (ATP) machines in cities.

(h) Replacement of bare LT conductors by Aerial Bunch Conductors (ABC) to prevent hooking and stealing of power in theft-prone areas.

(i) Provision of periodic checking of meters through accuchecks of all static and tri-vector meters installed in high value consumers' premises.

(j) Implementation of end-to-end solution with appropriate Information Technology (IT) intervention for integrating all key functions of the corporation, i.e. commercial, technical, finance, human resources, projects, etc.

3.8.3 Rural Electrification

Government of India has launched the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY) to electrify all villages and habitations, provide access to electricity to all households and give electricity connection to Below Poverty Line (BPL) families free of charge. The village and household electrification projects under RGGVY is expected to be achieved in 5 years through creation of Rural Electricity Distribution Backbone (REDB), Village Electrification Infrastructure (VEI) in each village and Decentralized Distribution Generation (DDG) systems, where grid supply is not feasible or cost effective. These schemes would also cater to the requirement of agriculture and other activities including irrigation pump sets, small and medium industries, khadi and village industries, cold storage chains, healthcare, education and IT to facilitate overall rural development, employment generation and poverty alleviation.

RGGVY is a Central Government sponsored scheme and `. 6438.3 Million are sanctioned to be available to UPCL for electrification of estimated total of 787 un-electrified villages, 682 de-electrified villages and 20,381 hamlets. 100% village electrification including un-electrified & de-electrified villages is expected to be done by March, 2010.

3.8.3.1 Franchisee Implementation

As per the Government of Uttarakhand mandate and in line with the provisions of RGGVY guidelines in an endeavor to improve operational and commercial efficiencies of the distribution system, raise the standard of services for increased customer satisfaction, especially in rural and hilly areas, increased participation of the local Non-Government organizations (NGOs) and self help groups and to ensure community participation in managing the franchisees and thereby generating employment opportunity in the hills. The

UPCL has decided to bring in revenue collection based franchisees at electricity sub-division level for distribution of electricity.

The aim of this initiative taken by the UPCL under RGGVY was to design and implement an institutional arrangement for ensuring sustainability of electricity supply, qualitative transformation of the electricity infrastructure to facilitate superior, social and economic outcomes by appointing franchisee in selected hilly and remote areas, largely through involvement of local population in the scheme.

3.8.4 LT System Strengthening

The UPCL has initiated a program with total outlay of ` 1500.0 Million for LT System strengthening and improvement works for the XIth Plan.

3.8.4.1 Segregation of private tube-well feeders

This scheme envisages construction of 11 kV line of 2727 km with conversion of existing 2430 km of LT line into HT line and installation of 2831 number of 11/0.4 kV distribution transformers of 25 kVA. The construction of 11 kV line of 900 km with conversion of 800 km of LT line into HT line and installation of 940 number of 11/0.4kV distribution transformers shall be provided for the segregation of Private Tube-Well (PTW) feeders during the year 2010-11.

3.8.5 Clean Development Mechanism Project

UPCL is implementing a pilot Clean Development Mechanism (CDM) project in distribution business by replacing existing incandescent bulbs with long life energy efficient compact fluorescent lamps across the grid connected domestic household in the chosen areas of the State. The project is being developed under the Ministry of Power, Government of India initiative called "Bachat Lamp Yojna (BLY)" which seeks to utilize CDM of the United Nations Framework of Climate Change Convention (UNFCCC) to reduce greenhouse gas emissions globally.

This project aims at sustainable development leading to social, economical and environmental benefits. It shall contribute to energy efficiency and reducing energy shortages during peak hours. On implementation of the project, there is potential to generate electricity savings of 60 GWH per year to UPCL. Also, savings in terms of additional investments required for setting up similar capacity power plants would accrue.

3.8.6 Commercial Process Improvement

UPCL has been implementing certain immediate commercial improvement measures in all its revenue division(s) / sub-division(s), including suitable modification of its existing processes with possible IT interventions for revenue cycle management, Management Information Systems (MIS) and consumer services enhancement. It has already initiated following commercial measures aimed at improving its revenue generation.

(a) UPCL has started Meter Reading Instruments (MRI) based centralized billing system for high value consumers (>25 kW) contributing to nearly 70% of revenue billing and collection. Besides, it has also initiated Automatic Meter Reading (AMR) system for implementation for all consumers above 4 kW by September, 2010 in phases. It will also facilitate energy audit and accounting through sub-station AMR System.

(b) Any Time Payment (ATP) machines.

(c) Bijlee Suvidha Kendra (BSK) as a single window consumer service centre.

(d) Key Consumer Cell (KCC) for revenue cycle management and better consumer service of all high value consumers.

(e) Online billing & Customer Relations Management (CRM) System.

(f) Effective meter-reading, bill distribution & disconnection.

(g) Bill collection –UPCL has taken following measures to facilitate better collection:

  (i) Payments through cheques in drop boxes and cash collection in banks.

  (ii) Mobile camps.

  (iii) Collection through post offices.

In order to facilitate speedy settlement of disputed electricity arrears in respect of industrial consumers, UPCL has constituted a corporate level dispute settlement committee in its head office. This initiative is aimed at reducing the number of disputed and legal cases without affecting the rights of consumers to seek justice from appropriate courts in the event of non-settlement.

3.8.7 Metering

Since its formation, UPCL is struggling to complete metering of all the consumers.

The summarized information on metering status as on 31 July, 2009 is shown in the Table 3.5 below:

Table 3.5: Status of metering in Uttarakhand

Category	Metered	Un-Metered	% of Metered Consumers	Total
Domestic	11,86,040	23,692	98.04%	12,09,732
Private Tube Well	17,530	3,307	84.13%	20,837
Other	1,49,541	-	100.00%	1,49,541
Total Consumers	13,53,111	26,999	98.04%	13,80,110

3.8.8 Strengthening of Distribution System

UPCL inherited an old and weak distribution network from UPPCL, requiring significant investments in order to provide uninterrupted and reliable power to its consumers. In the past years, some work has been done to strengthen the distribution system, particularly the HT distribution system through APDRP scheme of the Government of India [50]. But, the benefit of the scheme has not resulted in the improvement in the LT system, particularly in rural distribution system.

UPCL is witnessing a considerable growth in demand on account of massive rural electrification program as well as expected growth in demand from industrial consumers. Energy demand is expected to grow in 2011 in comparison to 2010 at the rate of 6.05%. In view of the above, there is a need for significant investments for strengthening as well as expanding the distribution network.

3.9 DEMAND SIDE MANAGEMENT MEASURES

After creation of the State of Uttarakhand, attractive electricity tariff along with other financial and fiscal incentive offered by the State Government, gave rise to interest amongst industries to start their operations in the State, which has resulted in tremendous increase in demand of electricity. As a result the fortuitous position of cheap and 24 hours supply witnessed in first six-seven years after creation of the State, has now changed to much costlier, unreliable and prone to power cuts supply. The projected gap between demand and supply can be reduced by either increasing the supply (Supply Side

Management) or by containing the Demand Side Management (DSM). Increasing the supply would require not only long gestation time and costly capital intensive investments, it would also consume scarce fossil fuels earlier. Hence it is right time now that utilities should start working on short term initiatives for DSM. It is in this context that the Commission thinks that the distribution licensee has to take lead in the same and, if required by taking help from Uttarakhand Renewable Energy Development Agency (UREDA). There is a win-win situation for both the utility and the consumer of electricity in adopting DSM techniques. The consumer benefited by reduced electricity bills, where as the utility enjoys reduced power purchase bill. The benefits of DSM can be summarized as below [169]:

- Reduction in customer energy bills.
- Reduction in the need for new power plant, transmission, and distribution network.
- Stimulating economic development.
- Creating long-term jobs due to new innovations and technologies.
- Increasing the competitiveness of local enterprises.
- Reduction in air pollution.
- Reduced dependency on foreign energy sources.
- Reduction in peak power prices for electricity.

Some of the common measures for DSM that can be taken up are:

- Reduction of technical and commercial losses of distribution system.
- Energy efficient pumps for lifting water.
- Use of Compact Fluorescent Lamps (CFLs)/Light Emitting Diode (LED) lamps in place of incandescent lamps for household, commercial, industrial and street lighting.
- Energy efficient lighting controls.
- Widespread use of solar water heating system for which capital and interest subsidies are also available.
- Replacement of existing magnetic ballasts with and use of electronic ballasts.
- Automatic power factor controllers.

- Energy efficient motors/fans including water pumping.
- Energy efficient transformers.
- Segregation of agricultural feeders.
- Energy audit of large government, commercial, and industrial consumer.

3.10 KEY MILESTONES IN THE REFORM

The provisions of open access, multiyear tariff plan, availability-based tariff structure and trading are the major break- through for the reform in Electricity Act, 2003.

3.10.1 Open Access

A licensee (i.e. Distribution, Transmission Company) can now allow Open Access to the transmission and distribution network in accordance with the provisions of Electricity Act, 2003 and SERC regulations. Under Open Access, a consumer seeks supply from some outside source, such as a generating company, captive power plant, or distribution licensee of some another area via that licensee's network. A generating company can also provide a supply to a consumer of another licensee's area under Open Access. The sole objective is to incorporate the additional generation into the network and minimize the gap of supply relative to demand. UERC laid down the principles, eligibility, procedure and charges for distribution and transmission Open Access in 2004 and 2005. UPCL has allowed open access to the distribution system since June 2004 [171]. The open access facility is subject to the terms and conditions of UERC and the distribution licensees, but till date no open access applications were reported in Uttarakhand.

3.10.2 Multi Year Tariffs

Rationalization of the tariff structure is a key factor in the reform of the power sector that allows the utility to recover its average cost of supply. Though the average cost of supply has increased over the years, some of the consumer categories continue to get subsidized power. UERC, in its guidelines to the Government of Uttarakhand (GoU) on reform of Uttarakhand State Electricity Board (USEB), indicated that while deciding the tariff, consumers' interests should be safeguarded. But the tariff should progressively reflect the costs of supply and competition, also efficiency, and economical use of resources should be encouraged. If utilities adopt a long-term Multi-Year Tariff (MYT) policy through the regulatory approach, it will not only give the necessary confidence to potential investors in the power sector, but also, GoU can estimate the funding required during the transition period in the form of subsidies for certain low income groups of consumers until the sector becomes self- sustaining. MYT plan is applicable to generating, transmission and distribution utilities. It is based on the performance parameter of the applicant within the stipulated control period, which in turn is based on forecasts made previously. The forecast is based on controllable as well as uncontrollable financial and technical parameters.

Average energy charges for all categories in 2005-06, 2006-07, 2007-08, and 2010-11 are summarized in Table 3.6. Constant increase in energy charges is observed during mentioned periods. On an average 38.70% increase in tariff is seen from 2005-06 to 2010-11. Relatively LT and HT consumers experienced greater increase in tariff as compared to other categories.

Table 3.6: Tariff structure for different categories of consumers from 2005-06 to 2010-11

Consumer categories	**2005-06** (`/kWh)	**2006-07** (`/kWh)	**2007-08** (`/kWh)	**2010-11** (`/kWh)	**%age change in tariff (2005-11)**
Domestic	1.94	1.89	1.82	2.37	22.16%
Non-domestic	3.33	3.41	3.37	4.23	27.02%
Public Lamps	2.50	2.50	2.50	3.28	31.2%
Private Tube Wells	0.70	0.70	0.70	0.68	-2.85%
Government Irrigation System	2.32	2.32	2.32	3.27	40.94%
Public Water Works	2.25	2.25	2.25	3.26	44.88%
LT Industry	2.45	2.45	2.45	3.96	61.63%
HT Industry	2.12	2.12	2.12	3.96	86.79%
Mixed Load	2.19	2.21	2.21	3.05	39.26%
Railway Traction	3.00	2.40	3.25	4.08	36.00%
Average	1.82	2.22	2.55	3.21	38.70%

Sources: UERC, 2005; UERC, 2006; UERC, 2008; UERC, 2010.

3.10.3 Availability Based Tariffs

ABT is a performance-based tariff for the supply of electricity which requires both generators and beneficiaries to commit to day ahead schedules. It is a system of rewards and penalties seeking to enforce day ahead pre-committed schedules, though variations are permitted if notified one and half hours in advance. It has three charges: fixed charge (FC), energy charge and unscheduled interchange (UI) charges. FC is payable every month by each beneficiary to the generator for making capacity available for use which varies with the share of a beneficiary in a generators capacity and with the level of availability achieved by a generator. An energy charge is for per kWh of energy supplied as per a pre-committed schedule of supply drawn upon a daily basis and UI charges for the supply and consumption of energy in variation from the pre-committed daily schedule. This charge varies inversely with the system frequency prevailing at the time of supply/consumption. Hence, it reflects the marginal value of energy at the time of supply. Since there is only one generating company in the State, UERC did not see any rationale for implementing ABT in the State.

3.10.4 Trading

Electricity Act, 2003 promotes trading and development of market in power. Accordingly, CERC have issued the detail guidelines for electricity trading and license. The features of trading are a distribution licensee does not require a license to undertake trading in electricity and National Load Dispatch Center (NLDC), Regional Load Dispatch Center (RLDC) and transmission licensee cannot engage in the business of trading in electricity [111]. Trading helps in resource optimization by facilitating disposal of surplus power with distribution utilities on the one hand and in meeting short-term peak demand on the other hand. The CERC and SERCs have powers to grant interstate and intra state trading licenses respectively. CERC granted license for inter-state trading in electricity to forty four firms by July 2009. Uttarakhand state policy allows power trading by UPCL and UJVNL, also has intention to create a power trading company in the near future. Presently no trading license exists in Uttarakhand state as on September 2010.

3.11 APDRP: A BRIEF ACCOUNT OF NEW PROJECTS OF THE STATE

The R-APDRP, introduced by GoI, is aimed at distribution improvement in terms of consumer indexing, asset mapping, GIS mapping of the entire distribution network, AMR System, SCADA system in big towns, feeder segregation, IT application for redressal of consumer grievances and integrated MR billing and collection, energy accounting and auditing, establishment of baseline data system. The part B of the R-APDRP includes projects for strengthening and improving the sub-transmission and distribution network by setting up of new 33/11 kV sub-stations, increasing capacity of 33/11 kV sub-stations, renovation of 33/11 kV sub-stations and equipment, renovating new 33kV overhead lines, augmentation of distribution transformers, up-gradation of feeders, load bifurcation. The program broadly envisages up-gradation and strengthening HT system network and shall cover major towns under 7 circles of UPCL. 31 towns with the resident population above 10,000 were identified under the R-APDRP aimed at reduction of the state-wise AT&C losses to below 15% by way of strengthening of the electricity distribution system and system improvement, new technology and IT initiatives and 3600 distribution system automation etc.

UPCL is also embarking upon a comprehensive distribution strengthening projects (including LT and HT) covering urban areas and already electrified rural areas. The project will also cover segregation of agricultural feeders from mixed rural feeders aimed at reduction of technical losses and improvement in quality and reliability of supply to consumers. The projects also encompass some focused commercial action plans targeted to reduce distribution losses and reduce AT & C losses. These projects are envisaged for implementation with funding assistance from financial institutions, i.e. REC / PFC / ADB and equity participation from the state government for implementation during 2011 to 2015.

3.12 CONCLUDING REMARKS

Reforms in the power sector, for making the sector efficient by introducing competition, have been in pipeline for several years and while there has been some progress, shortage of power and lack of access still looms large. The persistent shortages of electricity, both peak power and energy, indicate the need for improving performance of the power sector in the country. Power shortages are an indication of insufficient generating capacity and inadequate transmission and distribution networks. To a great extent this is the outcome of poor financial health of the State electricity utilities. APDRP is promoted with the mission to bring down AT&C losses but the actual performance has not come anywhere close to the targeted level. Appropriate energy audit distribution transformer wise, improved billing and collection efficiency, metering of each and every consumers will possibly help in reducing AT&C losses. The scope for further tariff increase is limited since tariffs for 'paying customers' are already among the highest in the world. The analysis shows that despite having an adequate legal framework for reform, the rate of implementation is low due to poor overall acceptance of the reform policies. Sector change has so far failed to create a strong beneficiary base through improved performance, better services and cost reductions. The overall progress of reform to date has so far failed to restore the creditworthiness of the power utilities. It has so far not brought about any tangible economic, financial social or environmental benefits. Micro level analysis carried out in the present work of Uttarakhand state electricity board also reveals the root causes of this ineffectiveness.

Furthermore, with the establishment of Regulatory Commissions and compulsory unbundling of all the State Electricity Boards, there is an urgent need for rigorous and in-depth study of performance of distribution utilities in India. Efficiency measurement would be of particular interest to the regulators in the open market regimes. Efficiency measurement will also form the core for introduction of the incentive based regulatory regimes and in promoting yardstick competition amongst the number of utilities. As the power utilities get progressively freed from the government control, the regulators would invariably require sophisticated benchmarking tools and methodologies to regulate the monopolies and to introduce incentive regulation while determining tariffs. Thus benchmarking the distribution enterprises would be a primary step in the direction of ensuring sustenance in the power sector. The subsequent chapters therefore, present a framework for benchmarking UPCL, Uttarakhand based on the data of the utility made available to us.

Chapter 4

INTROSPECTION OF RESTRUCTURING PROCESS OF AN INDIAN ELECTRIC UTILITY THROUGH EFFICIENCY EVALUATION AND PRODUCTIVITY ANALYSIS

4.1 INTRODUCTION

In the scenario of ever increasing energy demand, it has been an anathema for the power utilities of developing nations to operate and manage their power industries in efficient and economic way. In recent years, the power industry privatization and restructuring are gaining international importance as a measure to achieve this. Most of the Asian governments at present are preoccupied with designing and introducing reforms in their respective countries [139] with the objective to discover market oriented approach for electricity generation and supply and to introduce efficient natural monopoly activities in transmission and distribution [157]. India is no exception to this revolution in power sector. There have been significant changes in the Indian power sector since early 1990 [163]. The number of policies prompted by State Electricity Boards is due to continuous power shortage, poor operational performance and precarious financial situation of State electric utilities. These policy changes in relation to institution and regulation are expected to address the technical and financial challenges faced by the Indian Power Sector [17]. Due to the uninspiring financial position of the vertically integrated monolithic SEBs, the power sector was failing to attract the much needed investments for its development. However, these reform steps were not sufficient to bring about commercial viability of SEBs. This called for a focus attention to problems afflicting the customer and utility inter-face, i.e., the sphere of electricity distribution. In order to achieve commercial viability and to reduce AT&C losses of electric utilities, ministry of powers formulated a six level intervention strategy and to operationalise the strategy; ministry launched APDRP in the year 2000-01 [50].

Despite the realization of the importance of the distribution sector, performances of the distribution utilities have not been measured so far. Performance evaluation of electricity distribution utilities is an important issue as the electricity distribution not only involves various resources used on the production side, but also involves the considerations of consumers. The post Electricity Act, 2003 era has witnessed restructuring of power entities in India and the performances in the distribution need to be measured at priority in order to assess the impacts of reform measures initiated by Ministry of Power (MoP) and the International agencies.

In the era of restructuring and liberalization of the electricity market, the utilities need to focus on performance evaluation along with technological advancement and productivity enhancement to maintain competitive advantage. With the ongoing reforms in Indian power sector, therefore, it is crucial to analyze its past performances and productivity growth as such an analysis is likely to be vital for future improvement of the sector. This chapter therefore, analyzes efficiencies and productivities of the government owned electric utilities in the Post-Electricity Act 2003 era using DEA to derive the benchmarks based on the comparison of the EDDs of UPCL, Uttarakhand.

4.2 PERFORMANCE MEASUREMENT AND ANALYSIS: THE NEED

Performance evaluation through benchmarking of power utilities, in the overall context of infrastructure management is now perceived as an essential component of utility management. Efficiency and productivity are the most commonly used measure of performance in the electricity sector [98]. Such an appraisal is necessary not only to gauge the efficiencies of existing institutions, but also from a viewpoint of establishing goals and for refinement of basic institutions in conformity with the best practice to evolve better services and educate the stakeholders. The appraisal in itself is fairly attractive to all competitive utilities: the experience of companies in England and Wales has demonstrated that as companies gradually exhaust simple measures of cost reductions such as staff reductions, the trend is to look for formal benchmarking since all evidence from other privatized industries indicates that the cost reductions are actually achievable on a sustained basis [149]. Introducing the concepts of efficiency and effectiveness in power services has, therefore, assumed growing importance in the recent times.

Performance measurement approaches can provide relevant management information on extent of potential improvement. Pierce and Puthucheary [65] provide a general indication of how performance measurement may be used as a catalyst for changing organizational structure and improving utilities accountabilities.

For developing countries like India where resources and finances are scarce, efficiency induction in operation of services is of immense significance. The enhancement in utility efficiency may ultimately help to improve supply services, can lead to better operation and maintenance (O&M) and wider service coverage, resulting in reliable supplies at economic and affordable tariff. This is especially significant as in underdeveloped and developing economies like India a large number of poor reside, and to improve their economic standards, the reforms became crucial. Efficiency measurements for initiating corrective measures are therefore, very crucial for the electric supply sector in India.

Efficiency measurements in the Indian electricity distribution have been virtually non-existent so far. The service utilities limit themselves to some basic data collection at the local level so that performance may be assessed through compliance with defined technical standard supplemented by a few economic parameters derived from the balance sheets and the income statements. Efficiency estimation on a larger state, regional level is non existent so far. However, with the inception of Electricity Act, 2003, the scenario is now changing in India. Growing awareness about customer rights, customer dissatisfaction with the present state of management of many of the electric utilities and their technical and financial performances, coupled with the increasing realization that privatization of electric sector is sooner or later to become a reality, have forced government to take action and introduce reforms in an otherwise monopolistic sector. This also means, introducing the concepts of efficiency in electric services. Efficiency measurements for utilities have therefore, been recognized as an integral component of any reform program.

4.3 STAKEHOLDERS THAT REQUIRES EFFICIENCY ANALYSIS

Efficiency measures can be beneficially employed by a range of stakeholders to identify areas where there is scope for enhanced performance. Some of the areas that benefit from efficiency analysis are delineated below:

- A typical efficiency and productivity analysis will help managers and administrators to identify inefficient units. Also the utility managers can use efficiency measures to identify gaps between actual and existing best practices. These measures can thus form a useful part of benchmarking initiatives. Such an analysis can also help to identify performance targets based on which incentive schemes may be devised for managers to induce productivity.

- Regulators can use efficiency measures to implement incentive based regulations i.e. to identify and reward those service providers who are meeting their objectives in the most cost effective manner.
- Policy makers can assess the impact of reforms, such as output based funding or contracting out of service provisions.
- Community and business users can utilize the public information on performance of different service providers to keep governments accountable and force the decision making authorities to make favorable decisions with regard to their preferred service providers.
- Regulators can use these measures to assess the scope of further efficiency improvements and to determine if the electricity enterprises are exploiting monopoly power.
- Regulators can also employ these measures to set tariffs. Sustained improvement of efficiencies would be expected in competitive environments, but as of now, monopolistic like electricity supply face the fundamental issue of efficiency improvements by regulation. Incentive regulation or the Performance Based Regulation would also invariably involve determination of the efficiency or productivity factor, X, for defining tariffs. Benchmarking and efficiency analysis of electric utilities will help to set their X-factor. In this way, the model can act as an effective tool for developing a regulatory system that provides incentives for efficient practices.
- Efficiency measurements would be of particular interest to the regulators in open market regime by forming the core for introduction of the incentive based regulatory regime, and in promoting yardstick competition amongst utilities. As the electric utilities get progressively freed from the government control, the regulators would invariably require sophisticated benchmarking tools and methodologies to regulate the monopolies, encourage competition and to introduce incentive regulation while determining tariffs.
- Preferential allocation of the electricity sector funds for utilities that show inclination towards inducting efficiencies. Through such measures, the government can encourage the states to pursue reforms by providing easy loans and grants based on performance evaluations.

The Indian economy has opened up and is following a course of liberalization and reforms in the recent times. It is therefore, imperative that the infrastructure sector (which forms the core of all development) be made to grow to support the development process, would have to grow to ensure sustainability. So far there has been lot of stress on achieving wider coverage and ensuring reliable electricity services, but there has been virtually no effort on improving the levels of productivity in the electricity services as a whole. Thus, an urgent need exist for carrying out scientific analysis of performance evaluation using advanced benchmarking technique. The current work is an investigation in this direction.

DEA and TFP are two popular methodologies that can be employed in the power sector for efficiency and productivity analysis respectively. These techniques have been elaborated and its applicability to the Indian electricity sector has been demonstrated in the following sections.

4.4 BENCHMARKING METHODOLOGY EMPLOYED

There are several alternative methods that can be employed for performing efficiency and productivity analysis through benchmarking. Each method has its strengths and weakness, in term of necessary assumptions, technical properties and data requirements. Broadly, these are classified into two groups: the average and frontier methods. The average methods include simple comparisons, Ordinary Least Square (OLS), and TFP indices. Whereas Corrected Ordinary Least Square (COLS), SFA, and DEA are types of frontier methods. The average methods compare the target utility to some measure of average performance whereas the frontier methods compare the target utility to the most efficient comparable utilities. From a regulatory policy point of view, a major difference between frontier and average benchmarking is that the former has a stronger focus on performance variations between firms. Frontier methods can therefore, be used for setting firm-specific efficiency requirements. This approach can be suitable at the initial stages of regulatory reform when a priority objective is to reduce performance gap among the utilities [156].

The frontier methods create an efficiency frontier from a sample of utilities, which is then used as the benchmark against which performance of the target utility is measured. The inherent assumption behind the frontier methods is that all utilities in a selected sample should be able to operate at an efficiency level determined by the most efficient utilities in the sample. Among the frontier method, non-parametric DEA based on linear programming approach is a widely preferred method due to several reasons [7, 156]:

- It can be applied to analyze multiple outputs and multiple inputs without pre-assigned weights.
- Information required in DEA is less cumbersome.
- DEA is directly focused on frontier and efficiency estimation, rather than a central or biased tendency as an in Stochastic frontier measures.
- There is no prior assumption about the analytic form of the production function.
- It allows the use of environmental variables or variables not directly included into the production function but that have effects on the input/output ratio.

Another major advantage of DEA is that it does not require knowledge of the production function of the regulated firm, or the prices of the production function. DEA has therefore, been employed in this thesis for performance measurement of Indian electricity distribution utilities.

4.5 EFFICIENCY AND PRODUCTIVITY ANALYSIS OF ELECTRICITY DISTRIBUTION DIVISIONS

4. 5.1 Scope

DEA based efficiency evaluation and TFP has been applied in the literature to industries and whole economies. However, little work exists on distribution activities of electric power industry. This dissertation fills the gap on measuring overall efficiency and productivity change of government owned Indian distribution utilities.

This section examines the performance of the EDDs of UPCL- the State distribution utility of Uttarakhand has been carried out. UPCL is responsible for distribution of electricity in the state. Since inception, UPCL initiated several reform and restructuring steps. Facing the challenges of power industry development, UPCL devoted itself to establishing a technology-productivity-competitiveness oriented operating strategy to maintain its competitiveness in the power industry. To enhance the operational efficiency and productivity, UPCL disintegrated several EDDs into smaller ones. A benchmark approach is required to assess the relative performance of the EDDs that will be able to accommodate different type of inputs and outputs that coexists inherently in such systems. In the present work, DEA is applied to measure the relative efficiency of EDDs of Uttarakhand over a time period of four years, i.e. 2005-2008. Also productivity change is calculated for EDDs using a Malmquist TFP index for this period. Further, TFP is decomposed into technical efficiency change and technological change relying on a non-parametric DEA framework outlined by Fare et al. [134, 137].

4.5.2 Data and Methodology

4.5.2.1 Data source

Operational data of UPCL is recorded at two levels. Some data viz. Operating and Maintenance (O & M) cost are recorded at zonal Headquarters while the other data are recorded at the state Headquarter. All the data related to this study for the year 2005-08 have been collected from the two zones (Kumaon and Garhwal) and UPCL Headquarter [172]. The choice of year 2005-06 as the first period was decided from the data availability point of view. The choice of second period as year 2008-09 because the last published report till July 2010 available is up to this year only.

4.5.2.2 Input and output selection

Selection of input and output is the most important step in the process of performance evaluation. The choice of variables depends on not just the choice of methodology and technical requirement of the chosen model, but also on data availability and its quality, as well on country socio-economic structure. No universally applicable rational template is available for selection of variables. However, in general the inputs must reflect the resources used and the outputs must reflect the service levels of the utility and the degree to which the utility is meeting its objective of supplying electricity to consumers. A study of standard literature reveals significant insights into the choice of variables. Jamasb and Pollitt [156] outline the most widely used variables based on international experience.

The input/output selection for the present study made in view of those parameters that directly affect the consumers in terms of cost of electricity supply. The choice of variables was also based on the study of literature to sort out the right indicators from a potential group of parameters suggested in the survey by Jamasb *et al.* [155] and also insights given by Miliotis [113]. The variables were also finalized with help and advice from authority experts.

Operating and maintenance (O&M) cost is one of the most significant inputs for maintaining the EDDs under specific monetary value. O&M cost constitutes of Repairing and Maintenance (R&M) cost, and Administrative and General (A&G) cost. Apart from this, in the analysis of efficiency, number of employees is considered as an input which includes technical, non-technical and administrative staff, thereby giving them equal weights. The amount of electricity sold and number of customers are the two important output parameters in electricity distribution, since each customer has a particular pattern of electricity consumption and load characteristic [80, 81]. It is assumed that administrative employees required for each division is proportional to the number of customers and that the technical employees are proportional to the number of customers as well as to the total length of the network and total transformer capacity. Also network length is predominantly the factor of geographical characteristics and population density of the area served by a particular EDD. And transformer capacity is a factor of load forecast characterized by the type of consumers served by the divisions [113]. These two variables are outlets in the process of electrification and industrialization. Therefore, in this study distribution line length and transformer capacity are treated as outputs rather than inputs.

State of Uttarakhand has diverse geographical terrain with unevenly distributed population, therefore, to identify the effect of operating environmental conditions on the performance of divisions, inclusion of population density as a dummy variable would have produced a more realistic result but unfortunately the data was not available division wise for the analysis.

4.5.2.3 Methodology

DEA, basically developed by Charnes *et al.* [3], is a nonparametric approach for generating the efficiency frontier for the DMUs. It is a linear programming method that deals with the multiple inputs and multiple outputs without pre-assigned weights and without imposing any functional form on the relationships between variables.

Different assumptions of DEA are illustrated by considering an example of single input and single output. In Fig. 4.1 constant return to scale (CRS) and variable return to scale (VRS) DEA frontiers are drawn. A simple ray (OC) through the origin represents CRS frontier that envelops the data.

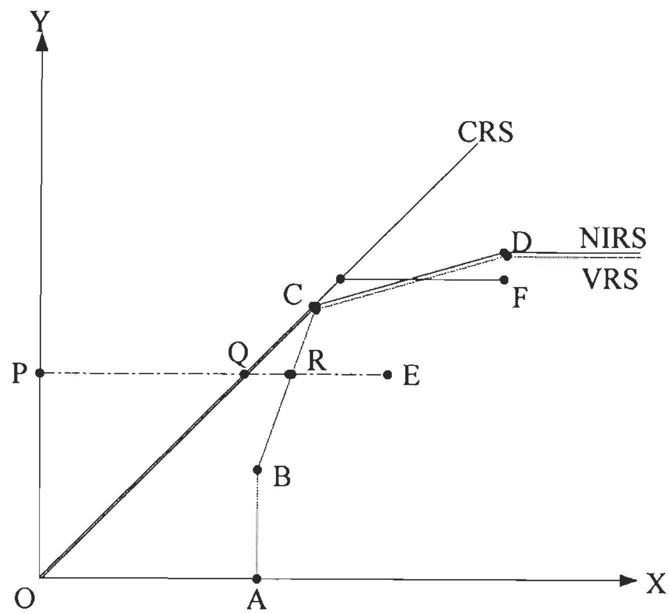


Fig. 4.1: Graphical illustration of different models of DEA (Input-oriented DEA using a single input to produce a single output)

The DMU at point C lie on the frontier and is termed as efficient DMU with efficiency score equal to one. DMUs (B, D and E) are identified as inefficient since they lie inside the frontier line. Overall efficiency of the inefficient DMU E can be defined as the ratio PQ/PE. However, CRS assumption is only appropriate when all DMUs are operating at an optimal scale. Imperfect competition, financial constraints etc. may cause a DMU not to operate at optimal scale. Banker, Charnes and Cooper [130] suggested an extension of the CRS DEA model to account for VRS situation. VRS decomposes the Overall Efficiency (OE) into Technical Efficiency (TE) and Scale Efficiency (SE). In Fig. 4.1, the piece wise linear frontier ABCD represents the VRS frontier line. The DMUs at point B, C and D lying on the VRS frontier and are designated as efficient with efficiency score equal to one. Technical efficiency for the inefficient DMU E is defined as the ratio PR/PE. The scale efficiency can be determined by dividing overall efficiency by technical efficiency. Further, by running additional DEA problem with non-increasing return to scale (NIRS) condition imposed, one can determine the current operating region of scale inefficient DMUs. The NIRS DEA frontier is also plotted in Fig. 4.1. The nature of the scale inefficiencies i.e. due to increasing or decreasing return to scale for inefficient DMUs can be estimated by seeing whether the NIRS efficiency score is equal to VRS technical efficiency score. And if they are unequal (as in case of DMU at point E in

Fig. 4.1), then increasing return to scale condition will exist. And if they are equal (as in case for point F in Fig.4.1), then decreasing return to scale will be applied.

4.5.2.3.1 The CCR model

CCR model was proposed by Charnes *et al.* [3]. It assumes CRS assumption. This model is found to be most suitable for DEA-based study of electric utilities by number of researchers [14].

The efficiency score in the case of multiple input and output factors is defined as:

$$\text{Efficiency} = \frac{\text{weighted sum of outputs}}{\text{weighted sum of inputs}}$$

The solution of DEA requires that the weights for inputs and outputs of each DMU be selected to maximize its efficiency under certain constraints. In other words, it allows each unit to pick most favorable weights for its specific situation. Thus, in mathematical terms the CCR model is given as:

$$Max\ \theta_0 = \frac{\sum_{r=1}^{s} v_r y_{ro}}{\sum_{i=1}^{m} u_i x_{io}} \qquad \ldots(4.1)$$

$$\text{s.t.} \quad \frac{\sum_{r=1}^{s} v_r y_{rj}}{\sum_{i=1}^{m} u_i x_{ij}} \leq 1, \quad j = 1,\ldots,n$$

$$u_i,\ v_r \geq 0, \quad \forall i, r$$

where, θ = The relative efficiency score;

y_{rj} = The amount of output *r* produced by DMU *j*;

x_{ij} = The amount of input *i* utilized by DMU *j*;

v_r = The weight given to the output *r*;

u_i = The weight given to the input *i*;

n = Total number of DMUs;

m = Total number of inputs;

s = Total number of outputs; and

o = designation unit for an optimization run, i.e., in each optimization run the efficiency of a specific unit is maximized and it is then repeated for all the units.

Instead of solving the problems as stated above, an equivalent model is usually solved since it requires lesser computations and is easier to implement. The equivalent representation is obtained by first converting the optimization problem into a linear programming (LP) problem which is given as:

$$\begin{aligned} &\text{Max} \sum_{r=1}^{s} v_r y_{ro} \\ \text{s.t.} \quad &\sum_{r=1}^{s} u_i x_{ij} = 1 \\ &\sum_{r=1}^{s} v_r y_{rj} - \sum_{i=1}^{m} u_i x_{ij} \leq 0; \qquad j = 1, 2, \ldots, n \\ &v_r, u_i \geq 0 \end{aligned} \qquad \ldots(4.2)$$

Duality principal is applied to the LP model. Dual is required as the number of constraints depends upon the number of inputs and outputs while number of constraints for primal depends on the number of DMUs, i.e., it reduces the number of constraints from $n+m+s+1$ in the primal to $m+s$ in the dual, thereby rendering the linear problem easier to solve [52]:

$$\begin{aligned} &Min\ \theta_0 \\ \text{s.t.} \quad &\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_0 x_{io}, \qquad i = 1, \ldots, m \\ &\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro,} \qquad r = 1, \ldots, s \\ &\lambda_j \geq 0, \qquad j = 1, \ldots, n \end{aligned} \qquad \ldots(4.3)$$

where, λ_j are the weights in the dual model for the inputs and outputs of the n units. The above stated linear programming is to be solved for each individual DMU in sample. The method construct frontier over the data points such that observed points lie on or below the production frontier. Efficiency scores are constructed by measuring how far utility is from the frontier. In general a DMU is efficient if efficiency score (θ) is equal to one and lie on the frontier, while efficiency score less than one indicates that the DMU is relatively inefficient.

4.5.2.3.2 Malmquist productivity index

In the energy sector, there is generally a great interest in investigating their productivity change over time. The nonparametric MPI is such a formal time-series analysis method for conducting performance comparisons of DMUs over time by solving some DEA-type models. This approach allows us to assess the relative importance of the catching up effects and the frontier shift effects resulting from reforms aimed at maintaining a competitive edge. Catching-up effects is disintegrated into technical efficiency effects and scale efficiency effects to bring clarity on the extent to which the efficiency gains are achieved from adjustments to input use or from better adjustment of division's size. The idea behind efficiency is to use data collected for the Electricity distribution divisions (EDDs), and to derive 'best practice frontier'. Production technology can change over time; therefore, it is important to incorporate this aspect of the production process and Malmquist total factor productivity index is one method applied in doing so.

The DEA method is used to compute a Malmquist index for measuring TFP growth. This provides evidence concerning patterns of total productivity growth and indicates whether productivity growth is due to catching up with frontier units or to technological change (frontier shift) over time.

To compute the above efficiency indices, Price and Weyman-Jones [26] show that the following linear programming problems are to be solved for each firm taken in turn.

Comparison of x_o^p at time period p to the frontier at time period q, i.e. calculation of $\theta_o^q(x_o^p, y_o^p)$ using the following input oriented CRS, DEA model:

$$\begin{aligned} & \theta_o^q(x_o^p, y_o^p) = \min \theta_o^{p,q} \\ \text{s.t.} \quad & \theta_o^p x_o^p - \sum_{j=1}^{n} \lambda_j^q x_j^q \geq 0 \\ & -y_o^p + \sum_{j=1}^{n} \lambda_j^q y_j^q \geq 0 \qquad \ldots(4.4) \\ & \lambda_j^q \geq 0, j = 1, \ldots, n \\ & p, q = t, t+1. \end{aligned}$$

The construction of Malmquist index requires computation of four CRS efficiency functions that can be solved through Eq. (4.3). By substituting $p = q = t$ in the above optimization problem, we can get efficiency value for DMUs in time period t relative to the time period t frontier $\theta_o^t(x_o^t, y_o^t)$. The relative efficiency of DMU in time period $t+1$

compared with the $t+1$ frontier, $\theta_o^{t+1}(x_o^{t+1}, y_o^{t+1})$, is calculated by setting $p=q=t+1$. By setting $p=t$ and $q=t+1$, we can find the efficiency of a DMU in time period t relative to the frontier at $t+1$, $\theta_o^{t+1}(x_o^t, y_o^t)$. Finally, when $p=t+1$ and $q=t$, we can evaluate the efficiency of a firm in time period $t+1$ relative to the frontier at time t, $\theta_o^t(x_o^{t+1}, y_o^{t+1})$.

Lam and Shui [123] applied DEA to measure the relative efficiency and productivity growth of China's thermal power generation. Chien *et al.* [22] developed an approach based on DEA and MPI to investigate the performance of power plants in China. Nakano and Managi [101] measured productivity in Japan's steam power generation sector. The input oriented Malmquist index of productivity change can be given as:

$$M_o = \left[\frac{\theta_o^t(x_o^t, y_o^t)}{\theta_o^t(x_o^{t+1}, y_o^{t+1})} \cdot \frac{\theta_o^{t+1}(x_o^t, y_o^t)}{\theta_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \right]^{1/2} \quad \ldots(4.5)$$

Following Fare *et al.* [132, 133], the above Malmquist productivity index can be written in an equivalent way which allows the decomposition of productivity change into change in technical efficiency and shifting of the frontier (technological change):

$$M_o = \frac{\theta_o^t(x_o^t, y_o^t)}{\theta_o^{t+1}(x_o^{t+1}, y_o^{t+1})} \cdot \left[\frac{\theta_o^{t+1}(x_o^{t+1}, y_o^{t+1})}{\theta_o^t(x_o^{t+1}, y_o^{t+1})} \cdot \frac{\theta_o^{t+1}(x_o^t, y_o^t)}{\theta_o^t(x_o^t, y_o^t)} \right]^{1/2} \quad \ldots(4.6)$$

The first term on the right hand side measure the magnitude of the efficiency change (effch) and second term measure technological change (techch) from time t to $t+1$.

Fare *et al.* [134] used VRS to further decompose the efficiency change (effch) into the pure technical efficiency change (pech) and the scale efficiency change (sech). Pure technical efficiency is also known as the managerial efficiency.

$$effch = \frac{\theta_o^{t(CRS)}(x_o^t, y_o^t)}{\theta_o^{t+1(CRS)}(x_o^{t+1}, y_o^{t+1})} \quad \ldots(4.7)$$

$$effch = pech \times \sec h \quad \ldots(4.8)$$

$$pech = \frac{\theta_o^{t(VRS)}(x_o^t, y_o^t)}{\theta_o^{t+1(VRS)}(x_o^{t+1}, y_o^{t+1})} \quad \ldots(4.9)$$

$$\sec h = \frac{\theta_o^{t(CRS)}(x_o^t, y_o^t) / \theta_o^{t(VRS)}(x_o^t, y_o^t)}{\theta_o^{t+1(CRS)}(x_o^{t+1}, y_o^{t+1}) / \theta_o^{t+1(VRS)}(x_o^{t+1}, y_o^{t+1})} \quad \ldots(4.10)$$

If value of the indices is greater than 1, then it means change is progressive and if less than 1, then it means that indices have been deteriorated from time t to $t+1$.

4.5.3 Results and Discussion

4.5.3.1 Efficiency analysis

As an attempt for power sector reform, UPCL resorting to disintegration of EDDs very enthusiastically, as it is obvious that managing small size division is relatively more convenient. The analysis exposed decrease in operational efficiency of EDDs post restructuring of the utility. Table 4.1 summarized the EDDs that disintegrated to form new divisions.

Table 4.1: Summary of EDDs that disintegrated into smaller divisions

EDDs	EDDs after disintegration	Year	Remarks
Dehradun (R)	Dehradun (R)	2006-07	One EDD disintegrated into two smaller divisions
	Vikasnagar		
Dehradun (N) Dehradun (S)	Dehradun (N)	2006-07	Two EDDs jointly disintegrated to form a new division
	Dehradun (S)		
	Dehradun (C)		
Roorkee (U)	Roorkee (U)	2006-07	One EDD disintegrated into two smaller EDDs
	Roorkee (R)		
Haridwar (U)	Haridwar (U)	2006-07	One EDD disintegrated into two smaller divisions
	Haridwar (R)		
Kashipur	Kashipur	2006-07	One EDD disintegrated into two smaller divisions
	Bazpur		
Rudrapur	Rudrapur	2006-07	One EDD disintegrated into two smaller divisions
	Sitarganj		
Srinagar	Srinagar	2008-09	One EDD disintegrated into two smaller divisions
	Pauri		

(R): Rural; (U): Urban; (N): North; (S): South; (C): Central.

Table 4.2 presents the overall efficiency for individual EDDs in Uttarakhand from 2005 to 2008. As shown in Table 4.2, the average efficiency score has decreased from 0.85 in 2005 to 0.772 in 2008. The result should have been other way round, as the state went through restructuring of electricity board in this period. One possible reason of this could be irrational restructuring of the distribution sector. Overall efficiency score can be observed to be varying in a wide spectrum across the EDDs. Only Dehradun (R) and Haridwar (U) divisions found to be operating along the production frontier in all years under observation. Some of the EDDs that disintegrated into smaller ones have achieved efficiency scores of 1. For example, Dehradun (R) division even after breaking into a new division, its overall efficiency remained unchanged during the period of analysis. On the other hand overall efficiency of Dehradun (N) and Dehradun (S) have been deteriorated from 2005-2008. And also overall performance of Dehradun (C) is not up to mark. Roorkee (U) and Haridwar (U) divisions are consistently performing relatively better than all other EDDs. Bazpur, Sitarganj, Roorkee (R) and Haridwar (R) divisions are identified as efficient from the year of their existence.

Table 4.2: Overall efficiency of EDDs for period 2005-08

S. No.	Circle/EDDs	Efficiency				Geography /Terrain
		2005	2006	2007	2008	
	EDC (R) Dehradun					
1	Dehradun (R)	1.000	1.000	1.000	1.000	Plain
2	Vikasnagar	-	0.906	0.883	0.621	Semi plain
3	Rishikesh	1.000	0.902	0.817	0.685	Semi plain
4	Uttarkashi	0.517	0.651	0.598	0.628	Hilly
	EDC (U) Dehradun					
5	Dehradun (N)	0.741	0.467	0.511	0.481	Semi plain
6	Dehradun (S)	0.856	0.649	0.670	0.664	Plain
7	Dehradun (C)	-	0.782	0.725	0.670	Plain
	EDC Srinagar					
8	Srinagar	0.827	0.701	0.948	1.000	Hilly
9	Pauri	-	-	-	1.000	Hilly
10	Tehri	0.905	0.763	0.753	0.875	Hilly
11	Gopeshwar	0.649	0.567	0.737	0.737	Hilly
12	Kotdwar	0.931	0.679	0.829	0.902	Semi plain
13	Rudraprayag	0.846	1.000	0.667	0.937	Hilly

	EDC Roorkee					
14	Roorkee (U)	1.000	1.000	0.967	0.964	Plain
15	Roorkee (R)	-	1.000	1.000	1.000	Plain
16	Haridwar (U)	1.000	1.000	1.000	1.000	Plain
17	Haridwar (R)	-	1.000	1.000	1.000	Plain
	EDC Haldwani					
18	Nainital	1.000	0.930	0.772	0.489	Hilly
19	Ramnagar	0.578	0.901	0.522	0.541	Semi plain
20	Haldwani (U)	0.612	0.651	0.541	0.508	Plain
21	Haldwani (R)	0.820	0.625	0.650	0.575	Semi plain
	EDC Rudrapur					
22	Kashipur	1.000	0.837	1.000	0.758	Plain
23	Bazpur	-	1.000	1.000	1.000	Plain
24	Rudrapur	1.000	0.849	1.000	0.940	Plain
25	Sitarganj	-	1.000	1.000	1.000	Plain
	EDC Ranikhet					
26	Ranikhet	0.804	0.654	0.755	0.727	Hilly
27	Almora	0.627	0.552	0.892	0.418	Hilly
28	Bageshwar	1.000	0.960	0.673	0.566	Hilly
29	Pithoragarh	0.883	0.810	0.749	0.818	Hilly
30	Champawat	0.962	0.829	0.843	0.651	Hilly
	Mean	0.850	0.816	0.810	0.772	-
	No. of EDDs	23	29	29	30	-

4.5.3.2 Productivity analysis

Notably, production technology might have changed during period 2005-08. Therefore, this study also applies the input-based Malmquist productivity index to investigate the productivity change of the divisions during period of analysis. Table 4.3 presents the statistical summary for technological change, efficiency change, pure efficiency change, scale efficiency change and total factor productivity change based on the Malmquist index for the period 2005-2008. The corresponding figures for the individual EDDs over the same period are shown in Table 4.4.

Table 4.3: Malmquist index of annual productivity change: 2005-2008

Year	effch	techch	pech	sech	tfpch
2005	1	1	1	1	1
2006	0.982	1.023	0.998	0.985	1.005
2007	1.064	0.910	1.068	0.996	0.968
2008	0.907	1.198	0.940	0.964	1.087
Annual Mean[a]	0.984	1.044	1.002	0.982	1.020

[a] The results are geometric means of individual indexes for all the EDDs excluding Vikasnagar, Dehradun (C), Roorkee (R), Haridwar (R), Bazpur and Sitarganj

Table 4.4: Malmquist index of annual productivity change for individual EDDs: 2005-2008

S. No.	Circle/EDDs	effch	techch	pech	sech	tfpch
	EDC (R) Dehradun					
1	Dehradun (R)	1.000	1.235	1.000	1.000	1.235
2	Vikasnagar[a]	1.000	0.971	1.000	1.000	0.971
3	Rishikesh	0.918	1.089	0.973	0.944	1.000
4	Uttarkashi	1.131	1.026	1.051	1.076	1.161
	EDC (U) Dehradun					
5	Dehradun (N)	0.890	1.107	1.013	0.878	0.985
6	Dehradun (S)	0.968	1.120	0.983	0.984	1.084
7	Dehradun (C)[a]	0.912	1.073	1.000	0.912	0.979
	EDC Srinagar					
8	Srinagar	1.065	1.032	1.018	1.046	1.099
9	Tehri	1.034	1.108	1.000	1.034	1.146
10	Gopeswar	1.077	1.095	1.075	1.002	1.179
11	Kotdwar	1.024	1.119	1.023	1.001	1.146
12	Rudraprayag	1.057	0.853	1.039	1.018	0.902
	EDC Roorkee					
13	Roorkee (U)	1.000	0.980	1.000	1.000	0.980
14	Roorkee (R)[a]	1.000	1.250	1.000	1.000	1.250

15	Haridwar (U)	1.000	0.823	1.000	1.000	0.823
16	Haridwar (R)[a]	1.000	1.197	1.000	1.000	1.197
	EDC Haldwani					
17	Nainital	0.843	0.913	0.883	0.956	0.770
18	Ramnagar	0.994	0.936	1.030	0.965	0.931
19	Haldwani (U)	0.945	1.068	1.005	0.949	1.019
20	Haldwani (R)	0.930	0.894	0.989	0.940	0.831
	EDC Rudrapur					
21	Kashipur	0.949	1.124	1.000	0.949	1.067
22	Bazpur[a]	1.000	1.004	1.000	1.000	1.004
23	Rudrapur	1.000	1.074	1.000	1.000	1.074
24	Sitarganj[a]	1.000	1.137	1.000	1.000	1.137
	EDC Ranikhet					
25	Ranikhet	1.007	1.097	1.000	1.004	1.106
26	Almora	0.906	0.982	0.939	0.965	0.889
27	Bageswar	0.911	1.087	0.968	0.942	0.990
28	Pithoragarh	1.042	1.115	1.040	1.002	1.163
29	Champawat	0.942	1.093	0.999	0.943	1.029
	Mean[b]	**0.982**	**1.037**	**1.001**	**0.982**	**1.019**

[a] The figures are estimates for the period 2006-2008. [b] The results are geometric means of individual indexes for all the EDDs excluding Vikasnagar, Dehradun (C), Roorkee (R), Haridwar (R), Bazpur and Sitarganj. The results of Malmquist index of annual productivity change for these six EDDs have been calculated in separate model.

It is clear from yearly distribution of the TFP indices (Table 4.3) that EDDs are having wide fluctuation during 2005-2008. Although overall they have been able to increase their productivity but unable to maintain their growth on yearly basis. Such fluctuations are common in DEA studies, since DEA method is much sensitive to year to year changes in inputs and outputs. The case of electricity industry is peculiar in the sense that utilities has fixed levels of capital and often fairly fixed level of labor endowment in the short run, but a fluctuating demand for their outputs (energy sold, number of consumers and network length etc.) over time. If the utility is showing recession, electricity sales may fall but inputs will not change very much, leading to fall in levels of efficiency and productivity. Alternatively, if the industry has under-utilized capacity and sales boom, then productivity levels will also rise significantly.

It can be observed from Table 4.3 and Table 4.4 that the TFP growth from 2005-2008 is 2 percent per year on average. Technological change is less than one in 2007, which implies that the distribution sector experienced technological regress during the period between 2006 and 2008. But technical efficiency improved during the same period as the value is greater than one. Fig. 4.2 represents the productivity growth of individual divisions from 2005 to 2008 while Fig. 4.3 represents the productivity growth of newly formed divisions from 2006 to 2008.

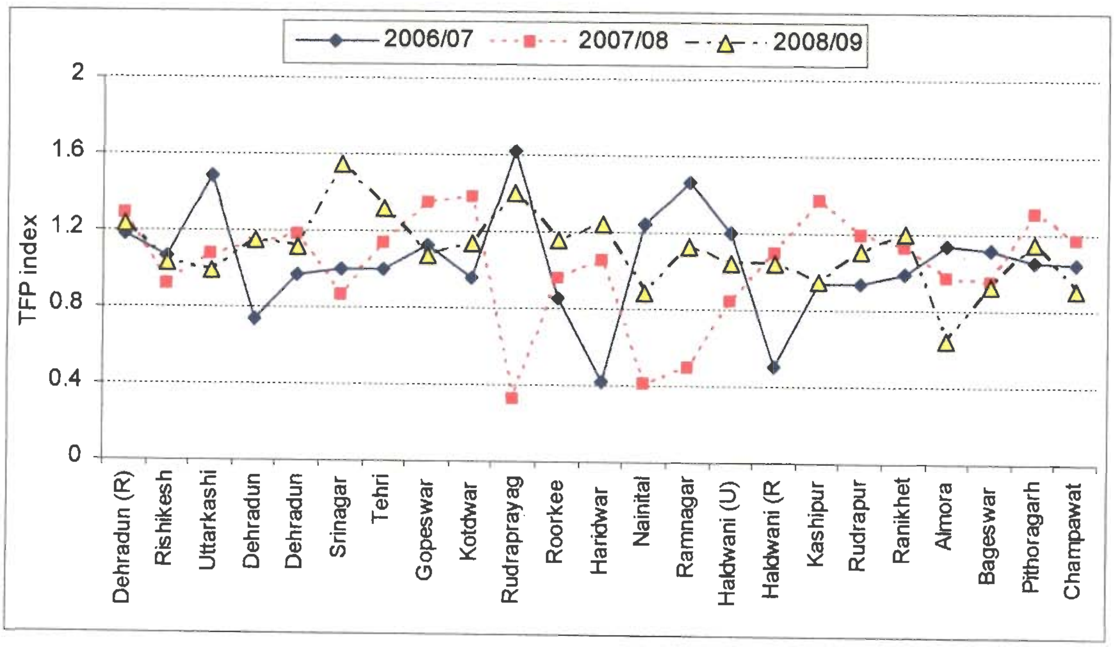


Fig. 4.2: Yearly TFP growth from 2005-2008

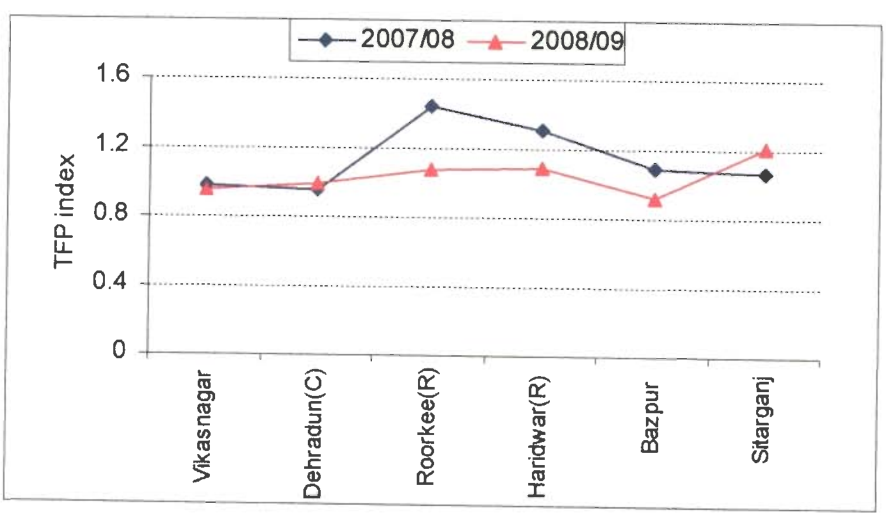


Fig. 4.3: Yearly TFP growth of new EDDs from 2006-2008

Dehradun (R) achieved highest total factor productivity growth of 23.5%. It is clear from MPI results that all the divisions of EDC Srinagar showed productivity growth during the period considered for analysis. Efficiency change and technological change both contributed to the productivity growth. Alternatively, divisions belonging to EDC Haldwani experienced productivity regress. Efficiency has deteriorated and accompanied by technological regress. This implies that they have been inefficient in integrating their resources and also lagging behind in utilization of technological innovations. When efficiency change is further decomposed into pure efficiency change and scale efficiency change, it is found that scale inefficiency is the main cause of overall efficiency degradation. So, result indicates that one way to improve the operational efficiency is to adjust the scale of operation of several EDDs.

4.5.4 Concluding Remarks on Efficiency and Productivity Analysis

DEA and MPI are applied in the present work to measure the relative efficiency and productivity growth of the EDDs of UPCL, respectively for the period 2005-2008. The study brings out that, although the state electricity board disintegrated several EDDs to enhance the overall productivity, but on contrary the average efficiency of the EDDs de facto dropped in the considered period. The overall efficiency had a mean score of 85% in the year 2005 which reduced to 77.2% for the year 2008. Therefore, while adjusting the production scale that possibly leads to progressive production technologies, greater attention should be paid to short-term managerial effort and operational adjustment. Without incorporating proper and effective short-term management, relative operational efficiency will decrease, damaging the total productivity improvement even when long-term strategic directions are correct. The productivity changes of the EDDs showed slight progressive development, but have been unable to sustain their growth and this need urgent attention of the policy makers. The TFP growth during the period of analysis found to be 2% per year on average. Technological change mainly accounted for the productivity growth which is due to investment in the electricity sector. At the same time efficiency change factor deteriorated mainly due to organizational structure and lack of competition among divisions. Further scale inefficiency was identified as main cause behind this deterioration. This analytical result provides decision makers with useful information regarding particular area to be considered in improving division's efficiency. This method can be adapted to monitor and diagnose productivity changes resulting from management decisions and the effectiveness of their implementations.

Chapter-5

A MICRO LEVEL STUDY OF AN INDIAN ELECTRIC UTILITY FOR EFFICIENCY ENHANCEMENT

5.1 INTRODUCTION

State Electricity Boards have been in existence for over 40 to 50 years, and have several achievements to their credit. However, on the whole SEBs had become unviable and unprofitable, with heavy accumulated losses and liabilities. They were blamed for poor service delivery, mainly due to inefficient planning and sluggish execution of capital works, inadequate maintenance, low generation (low PLF), high T&D losses, erratic supply to consumers, and perennial financial losses [175]. Such inept and consistently suboptimal performance on all fronts by the SEBs in general convinced the planners and policy makers about the need to reorganize the SEBs into smaller, viable, and uni-functional utilities, with clearly defined jurisdictions and tasks, as part of the power sector reforms. This hypothesis followed the realization that the earlier attempts to reform the generation segment of the electricity value chain had not achieved the desired results; and reforming the distribution segment was considered essential for improving the technical and financial performance, increased consumer care, corporatization of distribution segment and attracting significant private participation in the power sector. Once the unbundling has been carried out and the sector is reorganized, keeping track of the performance of the reforms and ensuring competition and efficiency in the sector should assume priority of the policy makers, planners and regulators. Benchmarking, as a technique for evaluation of performances across a number of utilities, is considered a potential methodology for efficiency improvements within organizations and sectors. In addition, by comparing the operating efficiencies of different distribution network owners with their national and international counterparts and with the best practices, it is possible to identify the scope for further efficiency improvements, and utilize the performance appraisal studies as a resource allocation tool.

In this chapter DEA, a non-parametric approach to frontier analysis, is applied to evaluate the relative performance of 29 EDDs for 2007-08 of an Indian hilly state, namely Uttarakhand. For productive restructuring, UPCL needs an effective benchmarking model to assess the relative performance of EDDs that is able to accommodate the different types of inputs and outputs which are inherent in such systems simultaneously. Input oriented DEA is applied to evaluate the relative overall efficiency, technical efficiency and scale efficiency of EDDs. Reliability of the CCR frontier divisions is examined for the same year. Further Slack analysis is carried out to formulate improvement directions for relatively inefficient divisions. Particular areas are identified, which are to be improved for overall efficiency enhancement through sensitivity analysis. Based on the efficiency analysis, this study investigates reorganization of inefficient EDDs to improve the operation efficiency of divisions. This micro level intra-state analysis based on DEA framework will reveal finer mechanisms causing inefficiencies and can throw some light on structural reasons for inefficiencies, an analysis that can greatly help in a voiding similar derivation of inefficiencies in the newly emerging regime of the power sector.

5.2 METHODOLOGY

5.2.1 CCR DEA Model

Methodology is same as discussed in Chapter 4 and Eq. (4.3) is used to calculate the CCR efficiency of the EDDs.

5.2.2 Slack Analysis

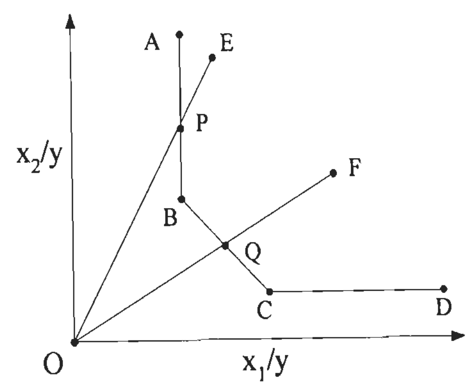


Fig. 5.1: Efficiency Measurement and Input Slacks

The piecewise linear arrangement of the non-parametric frontier in DEA can cause few difficulties in efficiency measurement. The linear frontier that runs parallel to the axes is the main cause of this difficulty [151]. In the example shown in Fig. 5.1, x_1 & x_2 are two inputs and y represents the corresponding output. A, B, C & D are four efficient DMUs which lie on the frontier whereas, E and F represents two inefficient DMUs. Point

P, the intersection point of line OE with the parallel piecewise linear frontier signifies the efficient point for the inefficient DMU E. From the Fig. 5.1, it is evident that same amount of output can be produced by shifting the point P to point B, i.e. by reducing the input by an amount of PB. This amount of reduction in input, which will produce the same amount of output, is defined as the input slack. If it was considered a case involving more inputs and/or multiple outputs, the diagram is no longer as simple, and possibility of the related concept of output slack also occurs.

Input and Output slacks may be calculated through following equations:

$$s_{io}^{-} = \theta_o x_{io} - \sum_{j=1}^{n} \lambda_j x_{ij}, \; i = 1,...m \qquad ...(5.1a)$$

$$s_{ro}^{+} = -y_{ro} + \sum_{j=1}^{n} \lambda_j y_{rj}, r = 1,...s \qquad ...(5.1b)$$

5.2.3 The BCC Model

Banker, Charnes and Cooper [130], has shown that when the DMUs do not perform at optimal scale, the CCR model can be modified to account for VRS conditions by adding a convexity constraint $\sum_{j=1}^{n} \lambda_j = 1$ to the CCR efficiency equation (i.e. Eq. 4.3).

The LP model employed to generate BCC efficiency is given as:

$$\begin{aligned} & \min \theta_0 \\ s.t. \quad & \sum_{j=1}^{n} \lambda_j x_{ij} \le \theta_0 x_{io}, \quad i = 1,...,m \\ & \sum_{j=1}^{n} \lambda_j y_{rj} \ge y_{ro}, \quad r = 1,...,s \\ & \sum_{j=1}^{n} \lambda_j = 1 \\ & \lambda_j \ge 0, \quad j = 1,...,n \end{aligned} \qquad ...(5.2)$$

In this model overall efficiency is decomposed into the technical efficiency measured by the BCC model and the scale efficiency. A DMU that is overall inefficient could be either technical inefficient or scale inefficient or both. Scale efficiency score of a DMU is the ratio of the overall efficiency to the technical efficiency. Therefore, a DMU is overall efficient if and only if it is technical and as well as scale efficient. The overall efficiency of a DMU equal to its technical efficiency, if the DMU is operating at the most productive scale size, and thus its scale efficiency is 1. Alternatively, if the scale efficiency is less than 1, the DMU will be operating either at decreasing return to scale or increasing return to scale.

To investigate further the current operating region to scale inefficient DMUs, Eq. 4.3 is modified with non increasing return to scale (NIRS) condition $\sum_{j=1}^{n}\lambda_j \leq 1$ imposed on it and given as:

$$
\begin{aligned}
&\min\ \theta_0 \\
&\text{s.t.}\quad \sum_{j=1}^{n}\lambda_j x_{ij} \leq \theta_0 x_{io}, \quad i = 1,\ldots,m \\
&\qquad \sum_{j=1}^{n}\lambda_j y_{rj} \geq y_{ro}, \quad r = 1,\ldots,s \qquad \ldots(5.3) \\
&\qquad \sum_{j=1}^{n}\lambda_j \leq 1 \\
&\qquad \lambda_j \geq 0, \quad j = 1,\ldots,n
\end{aligned}
$$

5.2.4 Reliability

As DEA is a statistical approach, skepticism about its stability and the extent of perturbation in the data observations, that can be tolerated before efficient DMUs is misclassified as inefficient, is often expressed. In the present study, we cite related work of Zhu [77], Seiford and Zhu [90, 91], Zhu [78] to develop necessary and sufficient conditions for preserving efficiency of the efficient DMUs and on this basis the entire stability region is obtained.

It is explicit that an increase of any output or a decrease of any input cannot deteriorate the efficiency of an efficient DMU (DMU_O) hence, we focus on upward (proportional) variations of inputs and downward (proportional) variation of outputs for DMU_0 and simultaneously vice-versa for other DMUs, i.e., downward variation of inputs and upward variation of outputs. The sensitivity analysis is based on a worst-case scenario, where efficiency of DMU_O deteriorates and the efficiencies of all other DMU_j $(j \neq o)$ improve. The subsequent changes (percent) of input (or output) of all DMU_j $(j \neq o)$ and DMU_O can be given as:

For an efficient DMU_o

$$\begin{cases} \hat{x}_{io} = \delta x_{io}, & \delta \geq 1, \quad i \in I, \\ \hat{x}_{io} = x_{io} & i \notin I \end{cases}$$

or
$$\begin{cases} \hat{y}_{ro} = \tau\, y_{ro}, & 0 < \tau \leq 1, \quad r \in O \\ \hat{y}_{ro} = y_{ro}, & r \notin O \end{cases}$$

For other DMU_j $(j \neq o)$

$$\begin{cases} \hat{x}_{ij} = x_{ij}/\delta, & \delta \geq 1, \quad i \in I, \\ \hat{x}_{ij} = x_{ij}, & i \notin I \end{cases}$$

or
$$\begin{cases} \hat{y}_{rj} = y_{rj}/\tau, & 0 < \tau \leq 1, \quad r \in O \\ \hat{y}_{rj} = y_{rj}, & r \notin O \end{cases}$$

where I and O denote the input and output subsets respectively under observation.

A linear programming (LP) model that is employed to fulfill the sensitivity analysis for input change case is given as:

$$\begin{aligned} & \beta^* = \min \beta \\ \text{s.t.} \quad & \sum_{\substack{j=1 \\ j \neq o}}^{n} \lambda_j x_{ij} - \beta x_{io} \leq 0, \quad i \in I, \\ & \sum_{\substack{j=1 \\ j \neq o}}^{n} \lambda_j x_{ij} - x_{io} \leq 0, \quad i \notin I, \\ & \sum_{\substack{j=1 \\ j \neq o}}^{n} \lambda_j y_{rj} - y_{ro} \geq 0, \quad r = 1, 2, \ldots, s, \\ & \beta, \lambda_j \, (j \neq o) \geq 0, \end{aligned} \qquad \ldots(5.4)$$

If $1 \leq \delta \leq \sqrt{\beta^*}$ is satisfied, then DMU_O remains efficient.

Similarly LP model required to fulfill the sensitivity analysis for output change case is given as:

$$\begin{aligned} & \alpha^* = \max \alpha \\ \text{s.t.} \quad & \sum_{\substack{j=1 \\ j \neq o}}^{n} \lambda_j y_{rj} - \alpha\, y_{ro} \geq 0, \quad r \in O, \\ & \sum_{\substack{j=1 \\ j \neq o}}^{n} \lambda_j y_{rj} - y_{ro} \geq 0, \quad r \notin O, \\ & \sum_{\substack{j=1 \\ j \neq o}}^{n} \lambda_j x_{ij} - x_{io} \leq 0, \quad i = 1, \ldots, m, \\ & \alpha, \lambda_j \, (j \neq 0) \geq 0. \end{aligned} \qquad \ldots(5.5)$$

If $\sqrt{\alpha^*} \le \tau \le 1$ is satisfied, then DMU_O remains efficient. β^* and α^* are the optimal values in Eq. 5.4 and 5.5 respectively.

It can be noticed that for any input and/or output change, LP models equations (5.4) and (5.5) employed may be infeasible. Seiford and Zhu [90] interpreted 'infeasibility' as 'stability' of the efficiency classification of test DMU.

5.3 SELECTION OF INPUT AND OUTPUT VARIABLES

Selection of input and output is based on the same approach as discussed in chapter 4 and mainly based on the work done by Miliotis [113]. As mentioned previously, this study uses monetary values of the input variables, this is particularly advantageous from a regulatory point of view, as monetary values of the inputs can reflect all operating and capital inputs and measure the relative cost efficiency of utilities.

Inputs:

x_1 : **O & M cost** (` Million); It includes Repairing and Maintenance (R&M) costs and Administrative and General (A&G) costs.

x_2 : **Number of employees;** It includes technical, non-technical as well as administrative employees.

Outputs:

y_1 : **Energy sold** (Million Units); It represents the energy sold annually in UPCL.

y_2 : **Number of customers;** It is the sum of connection points to supply power to the customers.

y_3 : **Average duration of interruption** (Hours); It includes shut down, break down and roastering types of interruptions (scheduled and unscheduled shut downs).

y_4 : **Distribution line length** (Circuit kilometer); It includes overhead network of 33 kV, 11 kV and LT lines.

y_5 : **Transformer capacity;** Transformer capacity is the sum of capacities of the transformers having voltage rating 11/0.433 kV.

Output is also characterized by certain quality measures; therefore, average duration of interruptions is included in this study as an important controllable output. Peak demand is not included as an output measure because a load curve for each division was not available. Annual data for duration of interruptions was not available therefore, monthly data is considered for this study. It is generated by averaging the interruption data of the month of May and October.

5.3.1 Preliminary Data Exploration

To substantiate the choice of variables (analytically), as being conducive to Indian conditions, a statistical analysis is carried out. Table 5.1 represents the statistical parameters evaluated for finding out the relevance of the choice of indicators for accessing the performance of EDDs.

Table 5.1: R^2 and ANOVA results

Dependent Variables	R^2	Adjusted R^2	F-ratio	Significance
O&M cost	0.515	0.410	4.887	0.003
Number of employees	0.541	0.441	5.415	0.002

- The R-squared of the regression is the fraction of the variation in the dependent variable that is accounted for (or predicted by) the independent variable.
- The F ratio is a measure of how much the model has improved the prediction of the outcome compared to the level of inaccuracy of the model [165].

R^2 values in Table 5.1 indicate that 51.5% of the variation in O&M cost and 54.1% of the variation in number of employees are subject to the five independent (predictors) variables; energy sold, number of customers, duration of interruptions, distribution line length and transformer capacity. Cross validity of this model can be assessed by comparing the adjusted R^2 values with that of observed value of R^2. In this case, they are found to be almost similar, hence validity of the model can be conferred to be good when R^2 is computed using Steins formula [8] to yield the adjusted R^2. The analysis of variance (ANOVA) results are also given in Table 5.1. This result with the independent variables indicate F ratio of 4.887 and 5.415 for the dependent variables O&M cost and number of employees respectively. Both F ratios are significant at $p<0.005$, which implies that there is less than 0.5% of chance that results would have come up in a random distribution, and there is 99.5% probability of being correct that the variables is having some effects and assumed that the chosen model is correct. Thus, in the proposed model the variables O&M cost and number of employees are well explained by the chosen independent variables.

An overview of the key characteristics of the data is presented in Table 5.2 in the form of mean, median, standard deviation, maximum and minimum values. In addition, according to Golany and Roll [18], the number of DMUs should be at least twice of the total number of input and output factors considered while using the DEA model. In this study the number of EDDs is 29, which is more than twice of the selected 7 input and output factors.

For the validation of DEA model, assumptions of the isotonicity relationships between the input and output factors was examined i.e., an increase in any input should not result in a decrease in any output [18]. If the correlation of the selected input and output factors is positive (0 to 1), then the factors are isotonically related and can be included in the analysis. And alternatively, when the correlation between input and output is negative, then the variable should be omitted from DEA analysis. Correlation coefficient for selected input and output factors is positive. Table 5.3 lists the correlation coefficients between the selected input and output variables.

Table 5.2: Summary statistics for the data

Variables	Mean	Median	Standard deviation	Minimum	Maximum
O&M Cost (` Million)	11.28	10.77	4.37	3.28	21.98
Number of Employees (Number)	148	144	51	57	254
Energy Sold (Million Unit)	156.29	148.24	146.64	19.66	674.39
Number of Customers (Number)	42428	44433	11922	16337	59796
Duration of interruption/feeder (Hours)	13.17	11.19	7.86	3.35	35
Distribution Line length (Circuit kilometer)	3863.66	2445.08	1804.17	359.26	7354.99
Transformer Capacity (kVA)	1176	1106	660	300	3242

Table 5.3: Correlation coefficient for inputs and outputs

Variables	X1	x_2	y_1	y_2	y_3	y_4	y_5
x_1	1.000						
x_2	0.476	1.000					
y_1	0.123	0.088	1.000				
y_2	0.574	0.645	0.339	1.000			
y_3	0.039	0.091	0.317	0.101	1.000		
y_4	0.643	0.592	0.045	0.490	0.240	1.000	
y_5	0.269	0.213	0.155	0.322	0.549	0.465	1.000

5.4 RESULTS AND DISCUSSION

5.4.1 CCR Formulation

The input oriented CCR model with constant return to scale is applied to determine the efficiency frontier for 29 EDDs. In this study the dual linear programming formulation of the CCR and BCC models were run 29 times by using DEAP Version 2.1, a computer program by Coelli [151].

Overall efficiency scores of all EDDs are given in Table 5.4. It is clear from the CCR result that only eight EDDs are identified as efficient with efficiency score equal to 1. And rests of the division are relatively inefficient having efficiency scores below 1. The average overall efficiency score of all the 29 divisions is 0.812, which reflect that there is greater room for efficiency improvement. It can be noticed that all the eight efficient divisions belongs to plain region. Fig.5.2 exhibits the structure of these eight efficient, which are the best ones and four worst performing utilities relative to the average performances of all utilities in CCR model. Performance of best, worst and their mean is plotted relative to the average performance of the entire sample, taking into account all the variables involved in this analysis. The plot provides a bird's eye view of important facts such as, the worst performing utilities are relatively utilizing higher O&M cost where as the quantity of output energy sold is relatively very low. None of the hilly area divisions are identified as efficient division and their efficiency scores lies between 0.598 and 0.948. Among all the hilly divisions, only Srinagar has high efficiency score of 0.948, which implies that the management is relatively good in terms of resource uses. Dehradun (N) has lowest efficiency score among all the 29 divisions, though it belongs to semi plain region. This implies that management is not appropriate in terms of resource utilization and needs improvement.

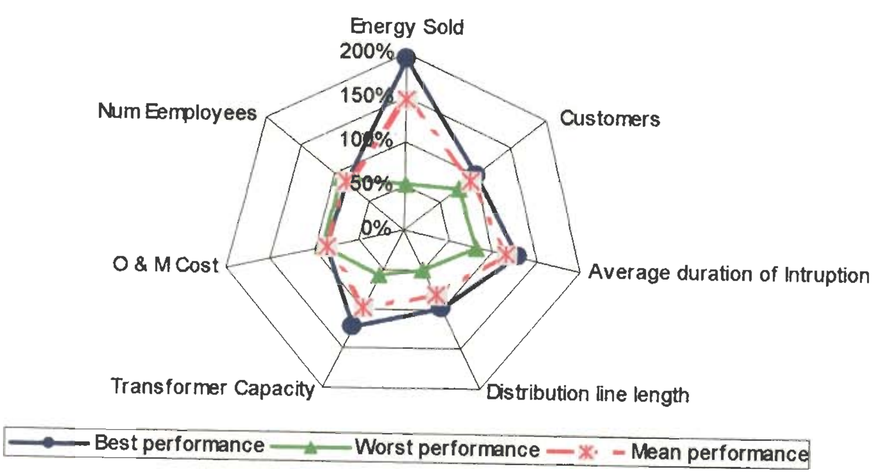


Fig. 5.2: Relative structure of best and worst performing EDDs

The inefficiencies among all the hilly divisions may be mainly due to poor load characteristics, adverse topographical features, harsh weather conditions, scattered households and low population density due to which power supply to hilly divisions are expensive and challenging.

To deal with the fact that the units may not operate under equivalent environmental terms i.e. the units corresponding to plain region and higher population density areas being in a more favorable position. Results of CCR model also supported this assumption. Therefore, to identify the effects of environmental conditions on the performance of EDDs, the EDDs are divided into two clusters. Cluster-1 includes only hilly divisions where as plain divisions constitutes Cluster-2.

For the validation of DEA model, the number of DMUs should be at least twice the number of selected variables [18], hence semi plain divisions are taken into account in both the Clusters. The efficiency of segregated EDDs into clusters is presented in Table 5.4. It can be seen from the result of cluster-1 that when hilly divisions are separated from plain divisions, they exhibited substantial increase in their efficiencies. The hilly divisions like Uttarkashi, Tehri, Srinagar, Rudraprayag, Pithoragarh and Champawat that were inefficient in the basic CCR model are now identified as efficient divisions in Cluster-1. Efficiency of all hilly divisions has increased and even semi plain divisions have become efficient except Dehradun (N) and Ramnagar with efficiency score of 0.720 and 0.777 respectively. In cluster-2, when plain divisions have been separated from the hilly divisions, no significant change is observed in their relative efficiency.

Thus, it can be concluded that when hilly and plain divisions are taken together for the efficiency evaluation, then environmental terms of plain divisions are more favored in comparison to hilly divisions. Efficient DMUs are designated as peers for inefficient DMUs. Inefficient DMUs can try to emulate their peers to improve their efficiency [141]. Peers for the inefficient divisions are listed in Table 5.4. For example, Dehradun (R) and Haridwar (R) are peers for Vikasnagar i.e., Vikasnagar can try to emulate its peers in order to register the values of indicators that will be considered best in the DEA study. However, there is lot of scope for the EDDs to improve their operational efficiency. In order to formulate the improvement directions slack analysis is carried out in the next section.

5.4.2 Slack Analysis

To improve the overall efficiency of inefficient divisions, a non-zero slack analysis is performed to calculate slacks in input and output factors. Since the analysis is input oriented, therefore only input slack has been mentioned. This analysis will provide possible improvement directions for the relatively inefficient divisions. The result of slack analysis is presented in Table 5.4. Slack in input factors represents the possible reductions in input factors for inefficient divisions to improve their efficiency.

It is observed that slacks for efficient divisions are zero. Slack in O&M cost is noticed for Rudraprayag, Pithoragarh and Champawat. And slack associated with number of employees is identified for ten divisions. For example, Bageswar can improve its efficiency by reducing its O&M cost by 1.585 ` Million and Almora can possibly increase its efficiency by eliminating 127 numbers of employees from its division.

Table 5.4: The results of CCR model and slack evaluation for input variables

Sl. No.	Circle/EDDs	Overall Efficiency	Peers	Cluster-1	Cluster-2	Input Slack Values		Geography/ Terrain
				Efficiency		O&M Cost	Employee	
	EDC (R) Dehradun							
1	Dehradun (R)	1.000	3		1.000	0.000	0	Plain
2	Vikasnagar	0.884	3, 8	1.000	0.884	0.000	17	Semi plain
3	Rishikesh	0.817	8, 22, 23	1.000	0.817	0.000	0	Semi plain
4	Uttarkashi	0.598	3, 8	1.000	-	0.000	23	Hilly
	EDC (U) Dehradun							
5	Dehradun (N)	0.511	8, 22, 23	0.720	0.511	0.000	0	Semi plain
6	Dehradun (S)	0.670	8, 23	-	0.670	0.000	0	Plain
7	Dehradun (C)	0.725	23, 8	-	0.725	0.000	0	Plain
	EDC Srinagar							
8	Srinagar	0.948	3, 8	1.000	-	0.000	115	Hilly
9	Tehri	0.753	8, 3	1.000	-	0.000	7	Hilly
10	Gopeswar	0.737	3, 8	0.862	-	0.000	39	Hilly
11	Kotdwar	0.829	8, 3, 25	1.000	0.829	0.000	8	Semi plain
12	Rudraprayag	0.712	3, 8	1.000	-	0.522	0	Hilly
	EDC Roorkee							
13	Roorkee (U)	0.967	8, 22, 7	-	0.967	0.000	0	Plain
14	Roorkee (R)	1.000	10	-	1.000	0.000	0	Plain
15	Haridwar (U)	1.000	7	-	1.000	0.000	0	Plain
16	Haridwar (R)	1.000	8	-	1.000	0.000	0	Plain
	EDC Haldwani							
17	Nainital	0.772	3, 8	0.870	-	0.000	48	Hilly
18	Ramnagar	0.522	23, 8	0.777	0.522	0.000	0	Semi plain
19	Haldwani (U)	0.541	8, 22, 23	-	0.541	0.000	0	Plain
20	Haldwani (R)	0.650	22, 23, 8	1.000	0.650	0.000	0	Semi plain

	EDC Rudrapur							
21	Kashipur	1.000	24	-	1.000	0.000	0	Plain
22	Bazpur	1.000	25	-	1.000	0.000	0	Plain
23	Rudrapur	1.000	22	-	1.000	0.000	0	Plain
24	Sitarganj	1.000	23	-	1.000	0.000	0	Plain
	EDC Ranikhet							
25	Ranikhet	0.755	3, 8	0.855	-	0.000	48	Hilly
26	Almora	0.892	3, 8	0.954	-	0.000	127	Hilly
27	Bageswar	0.673	10, 3, 8	0.919	-	1.585	0	Hilly
28	Pithoragarh	0.749	10, 3, 8	1.000	-	3.799	0	Hilly
29	Champawat	0.843	3, 8	1.000	-	0.000	5	Hilly
	Average	0.812		0.939	0.840	0.204	15	

5.4.3 Reliability

The reliability (sensitivity) analysis method is applied to the data sets of 29 EDDs of UPCL. The sensitivity analysis is carried out as follows: (i) percentage change in all the input and output subsets are considered; (ii) Upper-bond levels of $g_o (=\sqrt{\beta^*}-1)$ and $g \{=\left(\sqrt{\beta^*}-1\right)/\left(\sqrt{\beta^*}\right)\}$ for input change is determined. Similarly, for output change upper-bond levels of $h_o (=1-\sqrt{\alpha^*})$ and $h_o \{=(1-\sqrt{\alpha^*})/(\sqrt{\alpha^*})\}$ is calculated. Here, (g_o, g) and (h_o, h) can be interpreted as a sensitivity index in which g_o and h_o denotes the changes of each CRS-efficient EDDs under observation and g and h gives the changes in remaining divisions. These reliability indexes are used to check the robustness of the CRS-efficient EDDs.

Table 5.5 gives the summary of the reliability analysis of the eight CRS-frontier divisions in the year 2007. The rows represent 34 indices of different subsets of inputs and outputs related to these EDDs. The reliability index in each cell gives the upper bound levels of (go, g) and (ho, h). For example, consider EDD Kashipur, in the O&M cost row, (10.20%, 9.26%) means that the O&M costs in EDD Kashipur increased by 10.20% and subsequently the O&M costs in all other EDDs can be decreased by 9.26%. In all outputs row (2.57%, 2.65%) means that simultaneously 2.57% decrease in all outputs in EDD Kashipur and 2.65% increase of all outputs in the remaining EDDs cannot change the current efficiency categorization of EDD Kashipur. Efficiency measure for EDD Haridwar (U) and Kashipur appears relatively more sensitive to the possible data errors.

Table 5.5: Reliability measures for CCR efficient divisions

Input/Output	Name of CCR Efficient EDDs							
	Dehradun (R)	Roorkee (R)	Haridwar (U)	Haridwar (R)	Kashipur	Bazpur	Rudrapur	Sitarganj
x_1	R	R	2.37% [2.32%]	R	10.20% [9.26%]	R	R	R
X_2	R	24.39% [19.61%]	R	R	3.51% [3.39%]	12.09% [10.78%]	18.28% [15.45%]	R
All inputs	25.05% [20.03%]	24.39% [19.61%]	1.97% [1.93%]	49.57% [33.14%]	2.65% [2.58%]	12.09% [10.78%]	6.15% [5.79%]	9.65% [8.03%]
y_1	R	R	5.12% [5.39%]	R	6.22% [6.63%]	R	9.89% [10.98%]	23.37% [30.50%]
y_2	R	R	3.15% [3.25%]	R	5.12% [5.40%]	14.31% [16.71%]	R	R
y_3	R	R	R	R	R	R	R	R
y_4	24.16% [31.84%]	R	R	R	R	R	R	R
y_5	R	R	R	R	R	R	R	R
y_1+y_2	R	R	1.93% [1.97%]	R	2.77% [2.85%]	10.81% [12.12%]	9.89% [10.97%]	23.37% [30.50%]
y_1+y_3	R	R	5.12% [10.51%]	R	6.22% [6.63%]	R	8.12% [8.84%]	23.18% [30.17%]
y_1+y_4	23.98% [31.16%]	R	5.12% [5.39%]	R	6.22% [6.63%]	R	5.98% [6.36%]	22.99% [29.85%]
y_1+y_5	R	22.29% [28.69%]	5.12% [5.39%]	R	5.68% [5.93%]	R	9.89% [10.97%]	21.17% [26.86%]
y_2+y_3	R	R	R	R	5.12% [5.40%]	14.31% [16.71%]	R	R
y_2+y_4	22.08% [28.34%]	R	3.15% [3.25%]	R	5.12% [5.40%]	14.03% [16.31%]	R	R
y_2+y_5	R	R	3.15% [3.25%]	R	4.50% [4.72%]	14.31% [16.71%]	R	R
y_3+y_4	24.15% [31.85%]	R	R	R	R	R	R	
y_3+y_5	R	34.69% [53.13%]	R	R	R	R	R	R
y_4+y_5	24.15% [31.85%]	R	R	R	R	R	R	R
$y_1+y_2+y_3$	R	R	0.917% [0.925%]	R	2.77% [2.85%]	10.81% [12.12%]	8.12% [8.84%]	23.18% [30.17%]
$y_1+y_3+y_4$	23.98% [31.56%]	R	5.12% [5.39%]	R	6.22% [6.63%]	R	5.79% [6.15%]	35.98% [44.96%]
$y_1+y_3+y_5$	R	20.14% [25.22%]	5.12% [5.39%]	R	5.60% [5.93%]	R	8.12% [8.84%]	20.73% [32.99%]
$y_1+y_2+y_4$	20.28% [25.44%]	R	1.93% [1.97%]	R	2.77% [2.85%]	10.78% [12.08%]	6.06% [6.44%]	22.99% [29.85%]
$y_1+y_2+y_5$	R	22.29% [28.69%]	1.93% [1.97%]	R	2.57% [2.65%]	10.81% [12.12%]	9.89% [10.98%]	20.15% [25.23%]
$y_1+y_4+y_5$	23.98 [31.56%]	22.29 [28.69]	5.12 [5.39]	R	5.33 [5.63]	R	6.06 [6.44]	20.17 [25.23]

$y_2+y_3+y_4$	22.04% [28.27%]	R	3.15% [3.25%]	R	5.12% [5.40%]	14.03% [16.31%]	R	R
$y_2+y_3+y_5$	R	34.69% [53.13%]	3.15% [3.25%]	60.57% [153.64%]	4.50% [4.72%]	14.44% [16.85%]	R	R
$y_2+y_4+y_5$	22.08% [28.34%]	R	3.15% [3.25%]	R	4.50% [4.72%]	14.17% [16.51%]	R	R
y3+y4+y5	24.16% [31.85%]	32.76% [48.71%]	R	R	R	R	R	R
$Y_1+y_2+y_3+y_4$	20.03% [25.05%]	R	1.93% [1.97%]	R	2.77% [2.85%]	10.78% [12.08%]	5.79% [6.15%]	19.98% [24.98%]
$Y_1+y_2+y_3+y_5$	R	20.14% [25.22%]	1.93% [1.97%]	60.57% [153.64%]	2.57% [2.65%]	10.81% [12.12%]	8.31% [9.06%]	19.08% [23.57%]
$Y_1+y_2+y_4+y_5$	20.28% [25.44%]	22.29% [28.69%]	1.93% [1.97%]	R	2.57% [2.65%]	10.78% [12.08%]	6.06% [6.44%]	20.06% [25.09%]
$Y_1+y_3+y_4+y_5$	23.98% [31.56%]	19.61% [24.39%]	5.12% [5.39%]	R	5.33% [5.63%]	R	5.79% [6.15%]	16.83% [20.23%]
$Y_2+y_3+y_4+y_5$	22.07% [28.32%]	32.75% [48.71%]	3.15% [3.25%]	33.14% [49.57%]	4.50% [4.72%]	14.03% [16.31%]	R	R
All outputs	36.05% [45.08%]	19.61% [24.39%]	1.93% [1.97%]	33.14 [49.57%]	2.57% [2.65%]	10.78% [12.08%]	5.79% [6.15%]	16.83% [20.23%]

It should be noted that symbol 'R' means infeasibility (stability), i.e., (i) The input of the test EDD can be infinitely increased and simultaneously the corresponding inputs of the remaining DMUs can be reduced to any positive numbers, (ii) The output of the test EDD can be reduced to any positive number while the corresponding outputs of the remaining DMUs can infinitely be increased. It is evident that 48% reliability analysis cases are related with infeasibility, which implies that the CRS DEA model is stable to particular data error.

5.4.4 BCC Formulation

To find the causes of overall inefficiency, BCC model with variable return to scale is applied. The results of BCC model helps in identifying the major sources of inefficiency among the divisions and also provide improvement directions to promote the overall efficiency of inefficient divisions. The overall efficiency is decomposed into technical efficiency and scale efficiency and the nature of return to scale is presented in Table 5.6. Fig. 5.3 represents comparative structure of overall efficiency, technical efficiency and scale efficiency. A scale inefficient DMU that exceeds the most productive scale size (MPSS) will present decreasing return to scale. Alternatively, a scale inefficient DMU that is lower than the MPSS will present increasing return to scale.

Table 5.6: The results of BCC model

Sl. No.	Circle/EDDs	Overall Efficiency	Technical Efficiency	Scale Efficiency	Return to Scale
	EDC (R) Dehradun				
1	Dehradun (R)	1.000	1.000	1.000	Constant
2	Vikasnagar	0.884	0.885	0.998	Increasing
3	Rishikesh	0.817	0.836	0.976	Decreasing
4	Uttarkashi	0.598	0.633	0.944	Decreasing
	EDC (U) Dehradun				
5	Dehradun (N)	0.511	0.515	0.991	Increasing
6	Dehradun (S)	0.670	0.763	0.878	Decreasing
7	Dehradun (C)	0.725	0.844	0.859	Decreasing
	EDC Srinagar				
8	Srinagar	0.948	1.000	0.948	Decreasing
9	Tehri	0.753	1.000	0.753	Decreasing
10	Gopeswar	0.737	0.847	0.871	Decreasing
11	Kotdwar	0.829	1.000	0.829	Decreasing
12	Rudraprayag	0.712	0.793	0.899	Decreasing
	EDC Roorkee				
13	Roorkee (U)	0.967	1.000	0.967	Decreasing
14	Roorkee (R)	1.000	1.000	1.000	Constant
15	Haridwar (U)	1.000	1.000	1.000	Constant
16	Haridwar (R)	1.000	1.000	1.000	Constant
	EDC Haldwani				
17	Nainital	0.772	0.772	1.000	Constant
18	Ramnagar	0.522	0.586	0.890	Increasing
19	Haldwani (U)	0.541	0.542	0.998	Increasing
20	Haldwani (R)	0.650	0.666	0.976	Increasing
	EDC Rudrapur				
21	Kashipur	1.000	1.000	1.000	Constant
22	Bazpur	1.000	1.000	1.000	Constant
23	Rudrapur	1.000	1.000	1.000	Constant
24	Sitarganj	1.000	1.000	1.000	Constant
	EDC Ranikhet				
25	Ranikhet	0.755	0.782	0.965	Decreasing
26	Almora	0.892	0.900	0.991	Decreasing
27	Bageswar	0.673	0.699	0.963	Increasing
28	Pithoragarh	0.749	1.000	0.749	Decreasing
29	Champawat	0.843	0.844	0.999	Increasing
	Average	0.812	0.859	0.946	

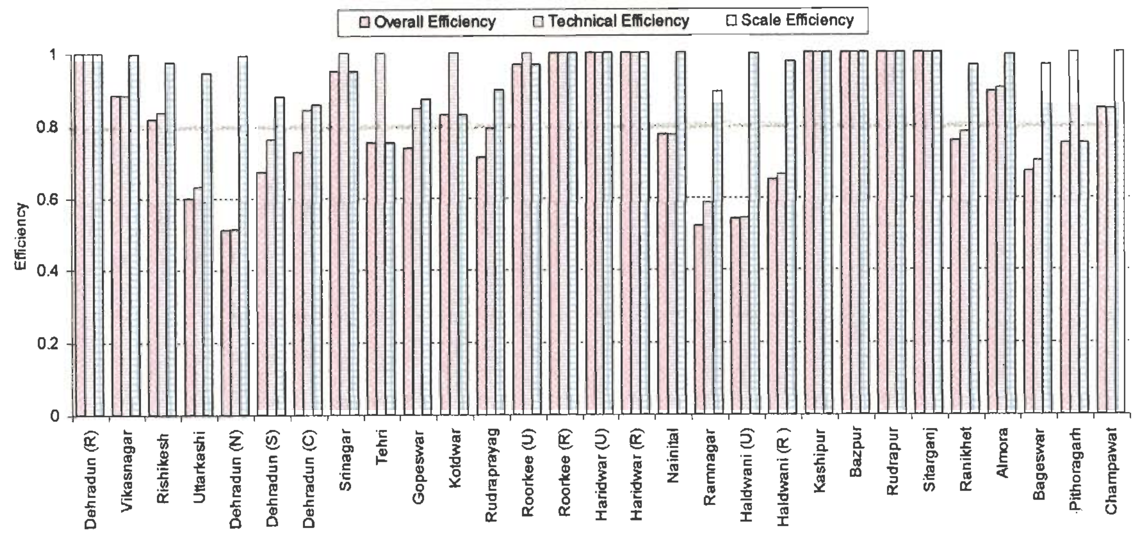


Fig. 5.3: Comparison of overall efficiency, technical efficiency and scale efficiency of divisions

For example, division Roorkee (U), Tehri, Srinagar, Kotdwar and Pithoragarh are technically efficient yet scale inefficient. These divisions can decrease their operational scale to improve the overall efficiency because they represented decreasing return to scale. The BCC result reveals that several EDDs are technically inefficient and their relative scales of operation have unbalanced status. After being separated from Uttar Pradesh, Uttarakhand Government has taken several measures to improve the operational efficiency of the UPCL. For the efficiency enhancement of distribution system, several divisions have been disintegrated, e.g. Vikasnagar is disintegrated from Dehradun (R) as a new division in the year 2006. Though Dehradun (R) has achieved their economy of scale and became efficient, but Vikasnagar became inefficient with increasing return to scale. This implies that its efficiency can be improved by increasing their scale size. Haridwar disintegrated into Haridwar (U) and Haridwar (R). Both divisions are efficient and operating at most productive scale size. Dehradun (C) is disintegrated from Dehradun (N) and Dehradun (S). All of them are identified as inefficient. Dehradun (N) is representing increasing return to scale. Also Haldwani has been disintegrated into Haldwani (U) and Haldwani (R). Both the divisions are inefficient and are exhibiting increasing return to scale which suggest that there is scope for increasing their scale of operation and thereby increasing overall efficiency. The above analysis indicates that arbitrary selection of divisions for the disintegration may not be productive. Results of BCC model will assist the managers to know the real status of scale of operation of inefficient EDDs and will help them for the further planning. It can be seen from Table 5.6 that the bigger EDDs like Uttarkashi, Tehri and Pithoragarh are inefficient mainly due to scale inefficiencies.

The result indicates the possibility of restructuring several utilities that evidently display low scale efficiency. The low value of scale efficiency and the fact that these utilities display either decreasing or increasing return to scale indicate that these divisions have considerable scope for improvements in their efficiencies by resizing their scales of operations to the optimal scale defined by most productive utilities in the sample. Thus, reorganizing the existing EDDs is one way to adjust the unbalanced scales of operation.

5.4.5 Sensitivity Analysis

In some situations a very low value of an input or a very large value of an output of a utility may mask its true efficiency and make it look efficient. Sensitivity analysis allows the analyst to perform "what-if" scenarios on DEA model. It involves investigating the effects on the solutions of making possible changes in the values of the parameters. The approach adopted here is based on removal of variables one by one from the data set to determine changes in DEA efficiencies, thereby checking the robustness of the DEA results. Note that efficiency either remains as it is or decreases on removal of variables.

On the basis of sensitivity analysis, divisions have been classified into different categories [14, 32].

- **Robustly efficient:** The DEA efficiency level at 1 or slightly below 1, when the variables are removed one at a time.
- **Marginally efficient:** The DEA efficiency is 1 for the base model and remains at one in some situation, but drops significantly in other situation.
- **Marginally inefficient:** The DEA efficiency if below 1 but above 0.9 for the base model and stays in that range during the sensitivity analysis.
- **Significantly inefficient:** The DEA efficiency is between 1 and 0.9 and drops to much lower values during the sensitivity analysis.
- **Distinctly inefficient:** The DEA efficiency is below 0.9 in all of the conditions.

In this study, overall efficiency is used in performing the sensitivity analysis. In particular, it was analyzed the differences of the relative efficiencies of the divisions by eliminating input and output variable one at a time from DEA model and the result is summarized in Table 5.7.

Table 5.7: Sensitivity analysis by elimination of variables

S. No.	Circle/EDDs	OE	x_1: W/O	x_2: W/O	y_1: W/O	y_2: W/O	y_3: W/O	y_4: W/O	y_5: W/O
	EDC (R) Dehradun								
1	Dehradun (R)	1.000	1.000	1.000	1.000	1.000	1.000	0.768	1.000
2	Vikasnagar	0.884	0.700	0.840	0.884	0.884	0.880	0.592	0.880
3	Rishikesh	0.817	0.690	0.773	0.706	0.524	0.817	0.817	0.817
4	Uttarkashi	0.598	0.462	0.598	0.598	0.598	0.598	0.381	0.597
	EDC (U) Dehradun								
5	Dehradun (N)	0.511	0.446	0.433	0.445	0.353	0.511	0.511	0.511
6	Dehradun (S)	0.670	0.667	0.412	0.670	0.484	0.670	0.670	0.670
7	Dehradun (C)	0.725	0.723	0.436	0.725	0.413	0.725	0.725	0.725
	EDC Srinagar								
8	Srinagar	0.948	0.489	0.948	0.948	0.945	0.948	0.741	0.948
9	Tehri	0.753	0.718	0.753	0.753	0.753	0.753	0.461	0.752
10	Gopeswar	0.737	0.558	0.737	0.737	0.737	0.737	0.490	0.737
11	Kotdwar	0.829	0.684	0.829	0.769	0.827	0.829	0.695	0.829
12	Rudraprayag	0.712	0.712	0.668	0.712	0.712	0.667	0.531	0.712
	EDC Roorkee								
13	Roorkee (U)	0.967	0.821	0.966	0.834	0.735	0.967	0.967	0.967
14	Roorkee (R)	1.000	1.000	0.755	1.000	1.000	1.000	1.000	1.000
15	Haridwar (U)	1.000	0.958	1.000	0.691	0.871	1.000	1.000	1.000
16	Haridwar (R)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	EDC Haldwani								
17	Nainital	0.772	0.492	0.772	0.772	0.771	0.772	0.469	0.772
18	Ramnagar	0.522	0.516	0.341	0.522	0.332	0.522	0.522	0.522
19	Haldwani (U)	0.541	0.526	0.415	0.533	0.308	0.541	0.541	0.541
20	Haldwani (R)	0.650	0.605	0.443	0.611	0.451	0.650	0.650	0.650
	EDC Rudrapur								
21	Kashipur	1.000	1.000	0.907	0.710	1.000	1.000	1.000	1.000
22	Bazpur	1.000	1.000	1.000	0.683	1.000	1.000	1.000	1.000
23	Rudrapur	1.000	0.959	0.961	0.721	0.881	1.000	1.000	1.000
24	Sitarganj	1.000	1.000	0.598	1.000	0.894	1.000	1.000	1.000
	EDC Ranikhet								
25	Ranikhet	0.755	0.523	0.755	0.755	0.754	0.755	0.477	0.755
26	Almora	0.892	0.346	0.892	0.892	0.889	0.892	0.618	0.892
27	Bageswar	0.673	0.673	0.511	0.673	0.666	0.673	0.565	0.651
28	Pithoragarh	0.749	0.749	0.519	0.749	0.740	0.749	0.633	0.721
29	Champawat	0.843	0.788	0.843	0.843	0.843	0.843	0.453	0.842
	Average	0.812	0.717	0.729	0.756	0.737	0.810	0.899	0.810

Result of sensitivity analysis shows that significant variation occurs in efficiency scores with elimination of different inputs and outputs. For example, though Bazpur division has an overall efficiency score of 1, it becomes 0.683 on excluding the energy sold factor, while the efficiency scores remain 1 in all other cases. Thus energy sold is strength of this division and hence Bazpur is categorized as marginally efficient division. Only Haridwar (R) division is identified as robustly efficient and its efficiency remains 1 for all conditions. None of EDDs falls under category of marginally inefficient. Roorkee (U) and Srinagar are significantly inefficient divisions. On eliminating O&M costs and distribution line length, significant decrease in efficiency is observed for division Srinagar. This implies that these two factors are advantageous factors for Srinagar and can play significant role in efficiency improvement. The classification scheme based on sensitivity analysis is illustrated by the graphical representation in Fig. 5.4, Fig. 5.5, Fig. 5.6 and Fig. 5.7.

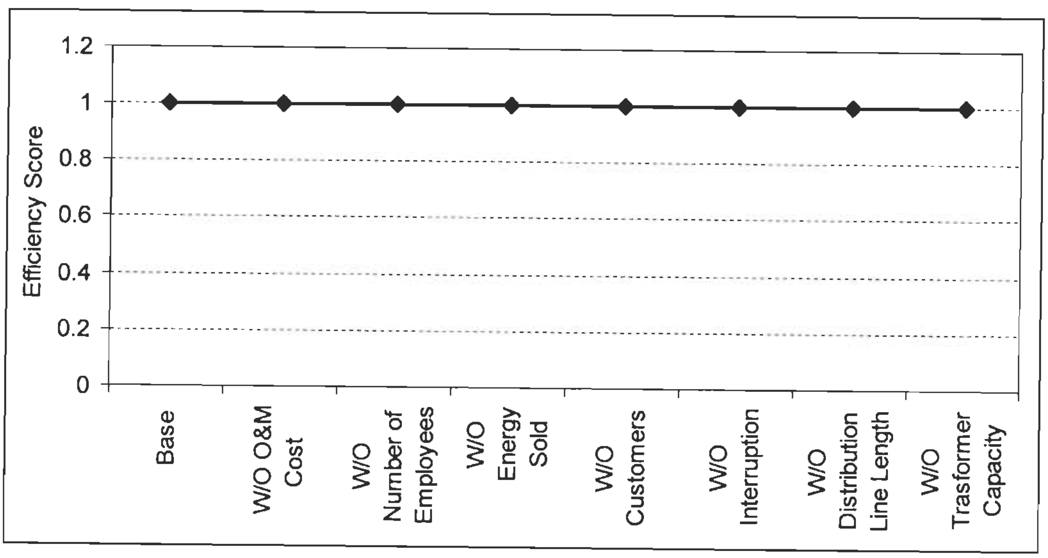


Fig. 5.4: Robustly efficient Haridwar (U)

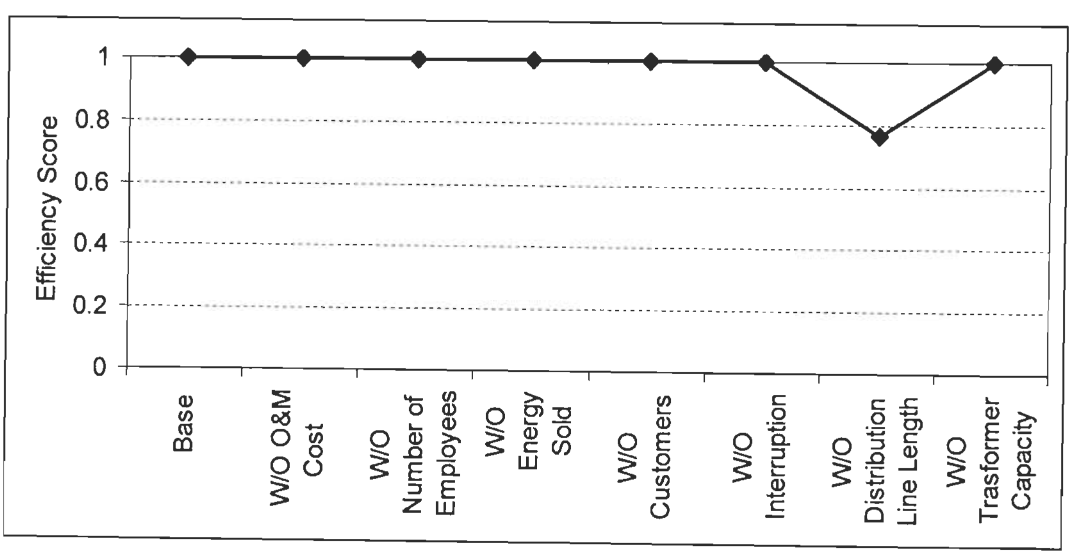


Fig. 5.5: Marginally efficient Dehradun (R)

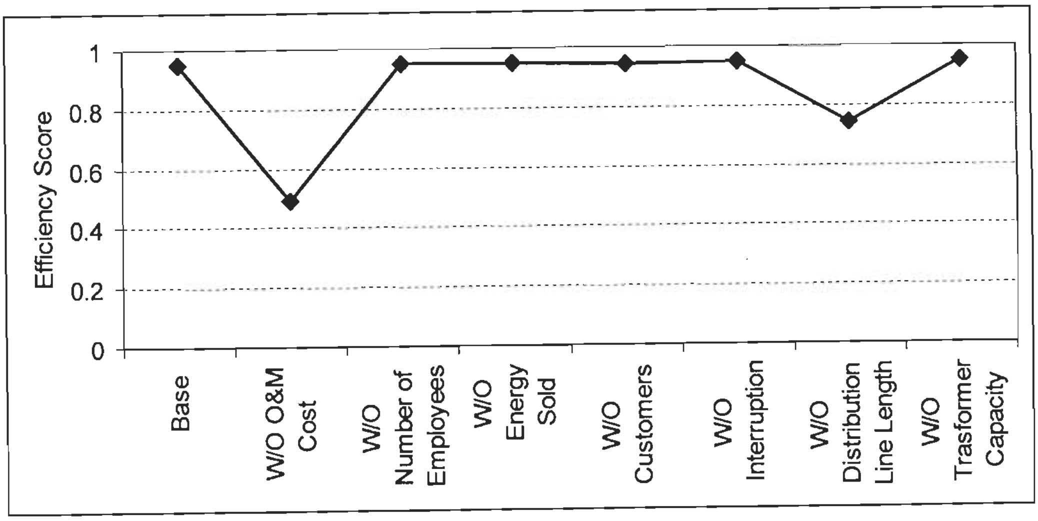


Fig. 5.6: Significantly inefficient Srinagar

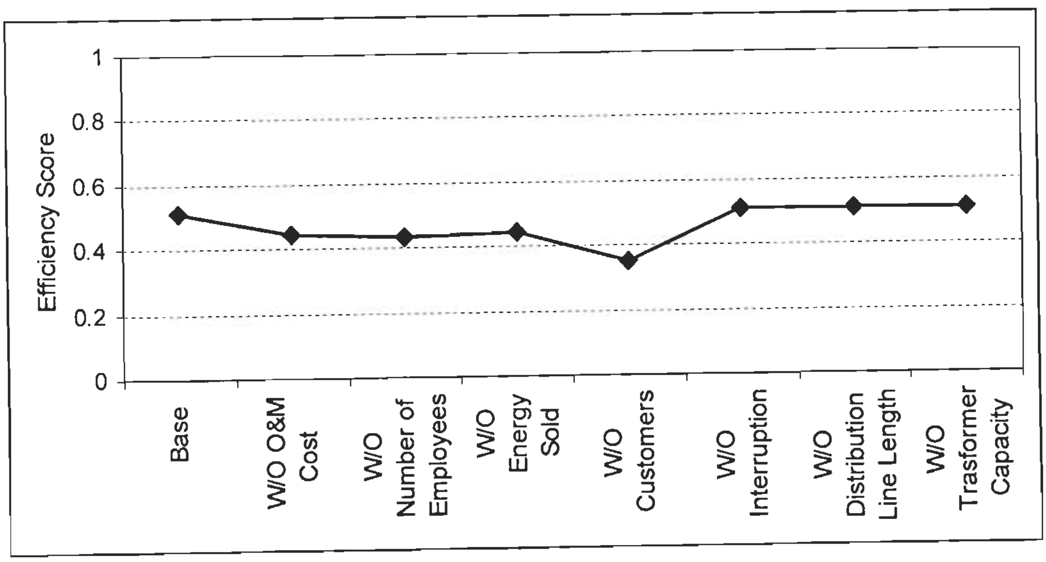


Fig. 5.7: Distinctly inefficient Dehradun (N)

Most of the divisions are distinctly efficient and need more attention and better insight for efficiency improvement. They are followed by marginally efficient and then significantly inefficient divisions. The factors required to increase the efficiency of individual divisions are identified. If efficiency of a division drops while conducting sensitivity analysis removing a certain variable, then that variable is considered to be the major variable to be changed for efficiency improvement of that division. It should be noted that input variables are to be reduced, while output variables are to be increased for improving the overall efficiency of EDDs. For example, Kotdwar could improve its efficiency by reducing its number of employees as well as increasing its energy sold and distribution line length. Similarly Kashipur could reduce its O&M cost and at the same time increase its energy sold to maintain its efficiency at one. In Table 5.8, divisions are classified into different categories and also variables are identified that should be considered for efficiency improvement.

Therefore, sensitivity analysis identifies the input and output factors that are advantageous for the corresponding divisions and suggest directions to allocate resources to maintain their competitive advantage.

Table 5.8: Classification of divisions based on sensitivity analysis

S. No.	Circle/EDDs	O E	Classification of EDDs	Variables to be considered For efficiency improvement
	EDC (R) Dehradun			
1	Dehradun (R)	1.000	Marginally efficient	Distribution line length
2	Vikasnagar	0.884	Distinctly inefficient	Number of employees, Distribution line length
3	Rishikesh	0.817	Distinctly inefficient	Number of employees, O&M Cost, Energy sold, Number of Customers
4	Uttarkashi	0.598	Distinctly inefficient	Number of employees, Distribution line length
	EDC (U) Dehradun			
5	Dehradun (N)	0.511	Distinctly inefficient	Number of employees, O&M Cost, Energy sold, Number of Customers
6	Dehradun (S)	0.670	Distinctly inefficient	O&M cost, Number of customers
7	Dehradun (C)	0.725	Distinctly inefficient	O&M cost, Number of customers
	EDC Srinagar			
8	Srinagar	0.948	Significantly inefficient	Number of employees, Distribution line length
9	Tehri	0.753	Distinctly inefficient	Number of employees, Distribution line length
10.	Gopeswar	0.737	Distinctly inefficient	Number of employees, Distribution line length
11	Kotdwar	0.829	Distinctly inefficient	Number of employees, energy sold, Distribution line length
12	Rudraprayag	0.712	Distinctly inefficient	O&M cost, Distribution line length

	EDC Roorkee			
13	Roorkee (U)	0.967	Significantly inefficient	Number of employees, energy sold, Number of customers
14	Roorkee (R)	1.000	Marginally efficient	O&M cost
15	Haridwar (U)	1.000	Marginally efficient	Number of employees, energy sold, Number of customers
16	Haridwar (R)	1.000	Robustly efficient	
	EDC Haldwani			
17	Nainital	0.772	Distinctly inefficient	Number of employees, Distribution line length
18	Ramnagar	0.522	Distinctly inefficient	O&M cost, Number of customers
19	Haldwani (U)	0.541	Distinctly inefficient	O&M cost, Number of customers
20	Haldwani (R)	0.650	Distinctly inefficient	O&M cost, Number of customers
	EDC Rudrapur			
21	Kashipur	1.000	Marginally efficient	O&M cost, Energy sold
22	Bazpur	1.000	Marginally efficient	Energy sold
23	Rudrapur	1.000	Marginally efficient	Number of employees, O&M Cost, Energy sold, Number of Customers
24	Sitarganj	1.000	Marginally efficient	O&M cost, Number of customers
	EDC Ranikhet			
25	Ranikhet	0.755	Distinctly inefficient	Number of employees, Distribution line length
26	Almora	0.892	Distinctly inefficient	Number of employees, Distribution line length
27	Bageswar	0.673	Distinctly inefficient	O&M cost, Distribution line length, Transformer capacity
28	Pithoragarh	0.749	Distinctly inefficient	O&M cost, Distribution line length
29	Champawat	0.843	Distinctly inefficient	Number of employees, Distribution line length

5.5 REORGANIZATION

Kao and Yang [23], have proposed different alternatives for reorganization of Forest Districts in Taiwan. Reorganization in distribution sector by comparing various alternatives based on the DEA results was given by Chien *et al.* [21] and Lo *et al.* [48], and reorganization of Credit Department of Farmers Association (CDFAs) in

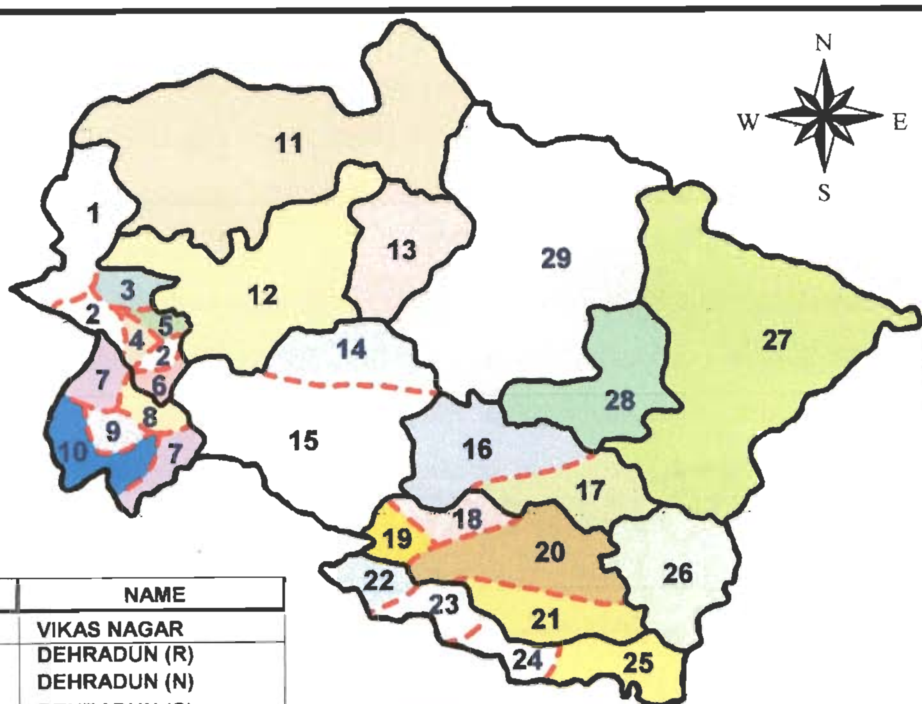
Taiwan [24]. So far reorganization alternatives based on DEA have not been proposed for Indian power sector.

UPCL is still in the process of restructuring the divisions through disintegration to improve the operational efficiency. Hence, it is relevant in practical context to investigate the reorganization of the divisions and propose some reorganization alternatives. Fig. 5.8 gives a map of Uttarakhand which represents location of all the 29 EDDs. General flow chart used for reorganizing the inefficient divisions is presented in Fig. 5.9, where C represents the total number of circles and Jc represents total number of DRS DMUs in the circle-c.

For adjusting scale of operation of EDDs in the proposed reorganizing algorithm, following criteria have been taken into account: first- EDDs should belong to same EDC, second-EDDs should be adjacent, and third-EDDs should have same geographical characteristics and should have good connectivity between them. Division's scale of operation is adjusted until becomes optimum.

Based on the algorithm depicted by flowchart (Fig. 5.9) EDDs are restricted and new alternatives are proposed in Table 5.9. For example, Pithoragarh is at decreasing return to scale and the two adjacent divisions Bageswar and Champawat are at increasing return to scale. When Bageswar is augmented by 11% of resources of Pithoragarh, Bageswar operates at optimum scale, similarly scale of Champawat becomes optimum when 8% of resources of Pithoragarh is added to it.

Three divisions -Tehri, Rudraprayag and Gopeshwar are contiguous and all of them are at DRS. Hence, a new division has been carved out from 33% resources of Rudraprayag and 30% resources of Gopeshwar. As a result Gopeshwar division becomes CRS. However, Rudraprayag division gets IRS status. Hence, in next step 33% resources of Tehri is merged with Rudraprayag division which makes all the three divisions operating at CRS. Similarly, using this algorithm six new EDDs (N_1-N_6) are curved out from their parent EDDs which were otherwise operating at decreasing return to scale. In EDC(R) Dehradun, EDD Uttarkashi at decreasing return to scale would have transferred some portion to Vikasnagar which is at increasing return to scale, but due to different geographical terrain and lack of good connectivity, these two EDDs are not considered for reorganization.



EDDs	NAME
1	VIKAS NAGAR
2	DEHRADUN (R)
3	DEHRADUN (N)
4	DEHRADUN (S)
5	DEHRADUN (C)
6	RISHIKESH
7	HARDWAR (R)
8	HARDWAR (U)
9	ROORKEE (U)
10	ROORKEE (R)
11	UTTARKASHI
12	TEHRI
13	RUDRAPRAYAG
14	SRINAGAR
15	KOTDWAR
16	RANIKHET
17	ALMORA

EDDs	NAME
18	NAINITAL
19	RAMNAGAR
20	HALDWANI (U)
21	HALDWANI (R)
22	KASHIPUR
23	BAZPUR
24	RUDRAPUR
25	SITARGANJ
26	CHAMPAWAT
27	PITHORAGARH
28	BAGESHWAR
29	GOPESHWAR

NOT TO SCALE

Fig. 5.8: Map of Uttarakhand Power Corporation Ltd. divisions

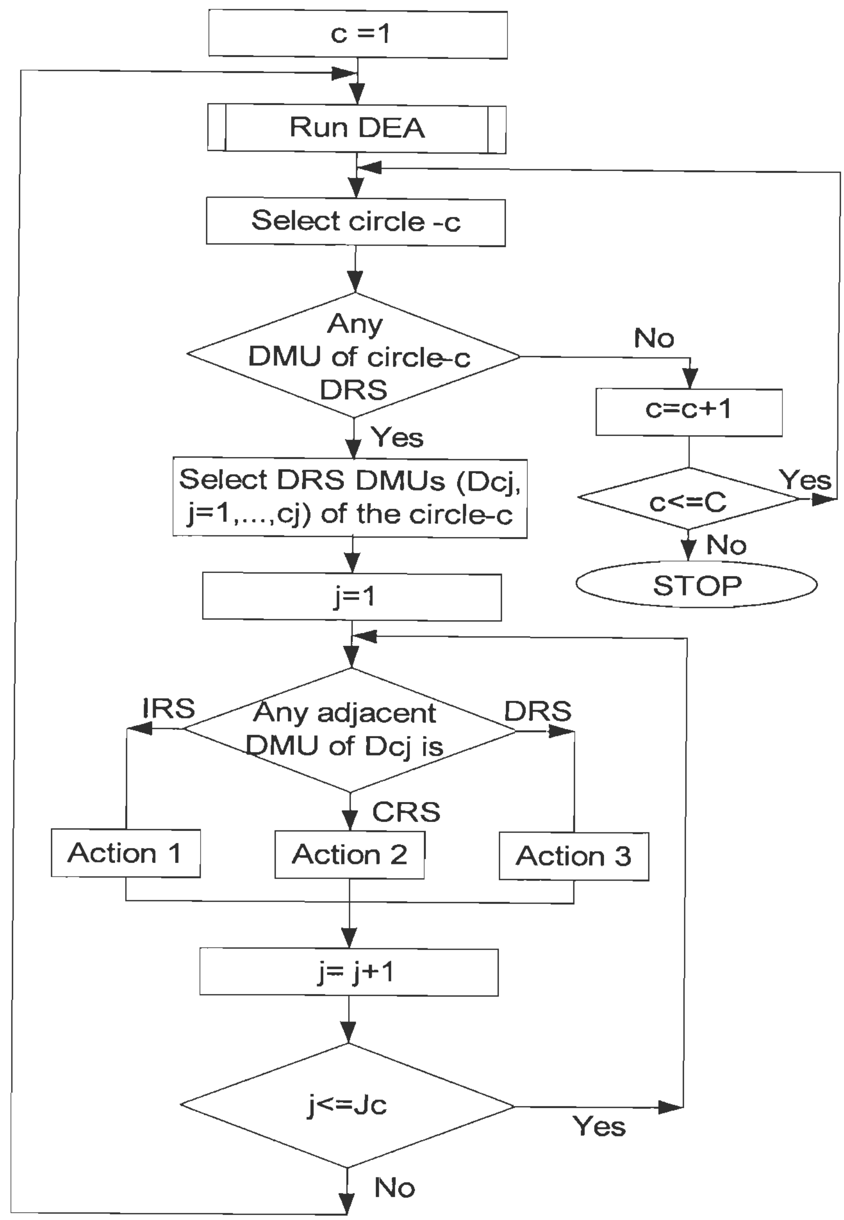


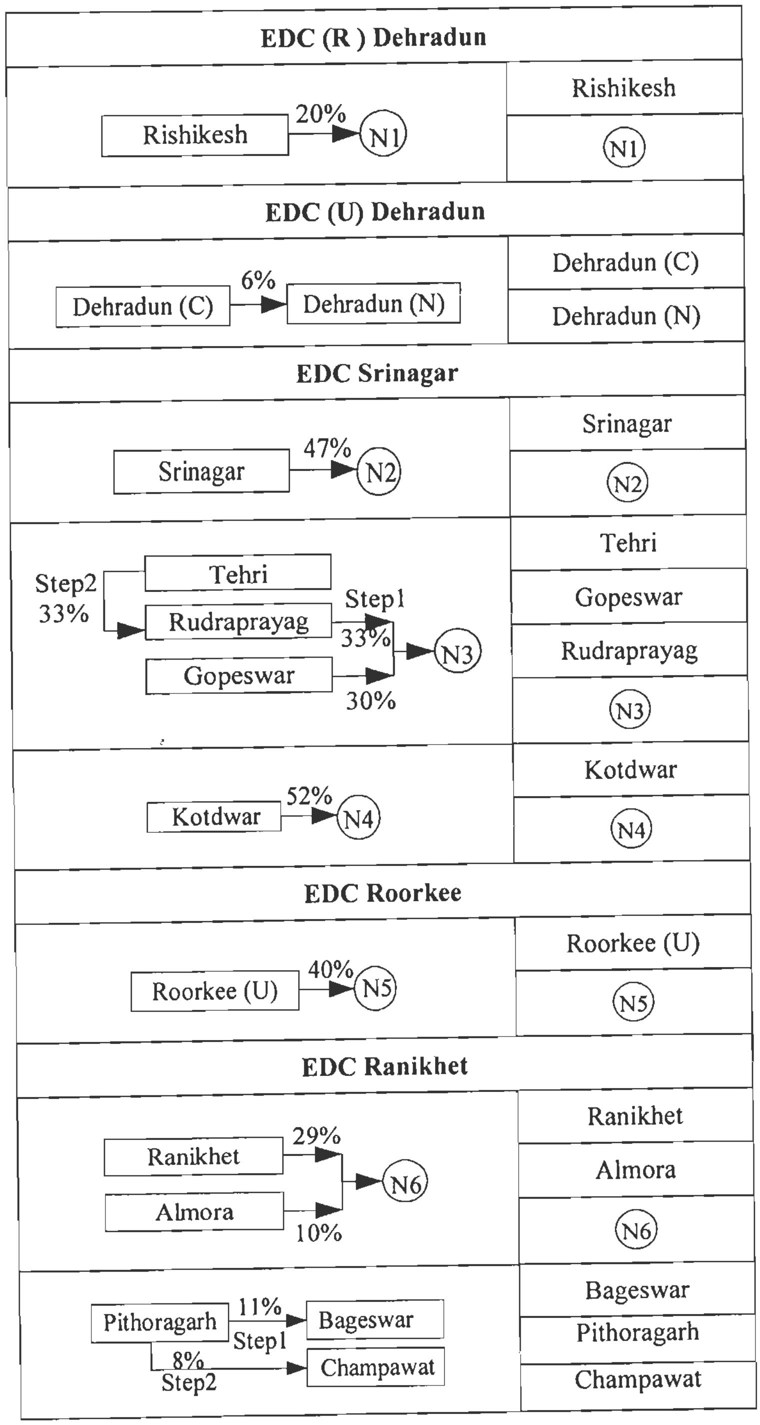
Fig. 5.9: Flow chart for reorganization of inefficient divisions

Action1 : Starting from substation that covers 1% of resources in form of input and output of DMU having DRS status is transferred to adjacent DMU having IRS status until any of the two achieve first CRS condition.

Action 2 : Starting from substation that covers 1% of resources in form of input and output of DMU having DRS status is disintegrated to form a new DMU until the DMU with DRS status achieve CRS status.

Action 3 : Starting from substation that covers 1% of resources in form of input and output of two adjacent DMUs having DRS status is disintegrated to form a new DMU until CRS condition is achieved

Table 5.9: Proposed reorganization alternatives



5.6 VERIFICATION OF THE PROPOSED MODEL

Table 5.10 presents overall efficiency, technical efficiency, scale efficiency and return to scale of modified EDDs along with the proposed new divisions. After reorganization of EDDs based on proposed algorithm, the average overall efficiency is observed to be increased from 81.2% to 81.6%. Also most of the newly formed divisions (except N6) are experiencing increasing return to scale. This implies that to maintain and develop the new divisions operational scale needs to be increased.

Table 5.10: Efficiency after reorganization of EDDs

S. No.	Circle/EDDs	Efficiency			Return to scale
		Overall	Technical	Scale	
	EDC (R) Dehradun				
1	Dehradun (R)	1.000	1.000	1.000	Constant
2	Vikasnagar	0.884	0.885	0.998	Increasing
3	Rishikesh	0.815	0.815	1.000	Constant
4	Uttarkashi	0.598	0.638	0.937	Decreasing
	EDC (U) Dehradun				
5	Dehradun (N)	0.522	0.522	0.999	Constant
6	Dehradun (S)	0.670	0.779	0.860	Decreasing
7	Dehradun (C)	0.724	0.808	0.897	Decreasing
	EDC Srinagar				
8	Srinagar	0.948	0.948	1.000	Constant
9	Tehri	0.753	0.753	1.000	Constant
10	Gopeswar	0.737	0.737	1.000	Constant
11	Kotdwar	0.829	0.829	1.000	Constant
12	Rudraprayag	0.700	0.700	1.000	Constant
	EDC Roorkee				
13	Roorkee (U)	0.966	0.967	1.000	Constant
14	Roorkee (R)	1.000	1.000	1.000	Constant
15	Haridwar (U)	1.000	1.000	1.000	Constant
16	Haridwar (R)	1.000	1.000	1.000	Constant
	EDC Haldwani				
17	Nainital	0.772	0.772	1.000	Constant
18	Ramnagar	0.522	0.543	0.961	Increasing
19	Haldwani (U)	0.541	0.542	0.999	Increasing
20	Haldwani (R)	0.650	0.657	0.989	Increasing
	EDC Rudrapur				
21	Kashipur	1.000	1.000	1.000	Constant
22	Bazpur	1.000	1.000	1.000	Constant
23	Rudrapur	1.000	1.000	1.000	Constant
24	Sitarganj	1.000	1.000	1.000	Constant

	EDC Ranikhet				
25	Ranikhet	0.755	0.755	1.000	Constant
26	Almora	0.892	0.892	1.000	Constant
27	Bageswar	0.684	0.684	1.000	Constant
28	Pithoragarh	0.747	0.780	0.958	Decreasing
29	Champawat	0.800	0.800	1.000	Constant
30	N1	0.821	1.000	0.821	Increasing
31	N2	0.948	0.948	0.999	Increasing
32	N3	0.715	0.716	0.999	Increasing
33	N4	0.970	1.000	0.970	Increasing
34	N5	0.778	0.783	0.994	Increasing
35	N6	0.829	0.840	0.988	Decreasing
	Mean	**0.816**	**0.831**	**0.982**	

In Fig. 5.10 performance of six new divisions in terms of overall, technical & scale efficiency is plotted against their respective existing mean scores and observed change in efficiency is also represented. It can be noted from the Fig.5.10 that all the new divisions (except N_3 & N_5) have higher overall efficiency as compared to mean efficiency score of existing divisions. Low overall efficiency in N_3 & N_5 is due to low technical efficiency.

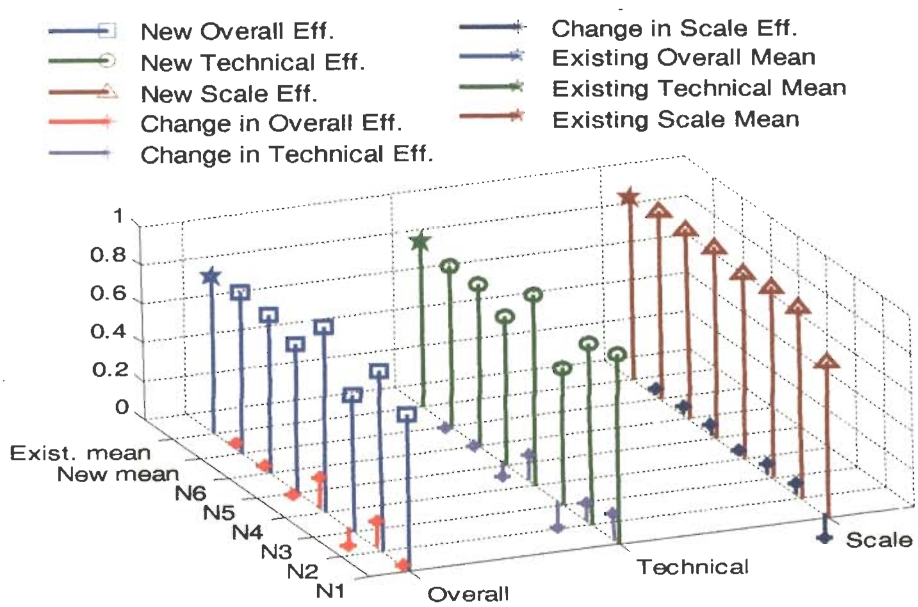


Fig. 5.10: Comparison of efficiencies of new divisions with existing divisions

In Fig. 5.11, different mean scores with their respective standard deviation of the existing system and reorganized system are compared. It is clear from Fig. 5.11 that overall and scale score means of new divisions is higher with lower/better standard deviation as compared to its respective existing mean. Alternatively, mean technical efficiency of new divisions found to be lower than existing mean. It may be possibly due to disintegration process and can be improved through proper allocation of resources by management. It can be achieved through measures like energy accounting and auditing, managerial initiatives by engaging in direct training, evaluation activities, feedback process, and reward and recognition mechanism. Also through adoption of information technology for improving efficiency and enhance consumer satisfaction.

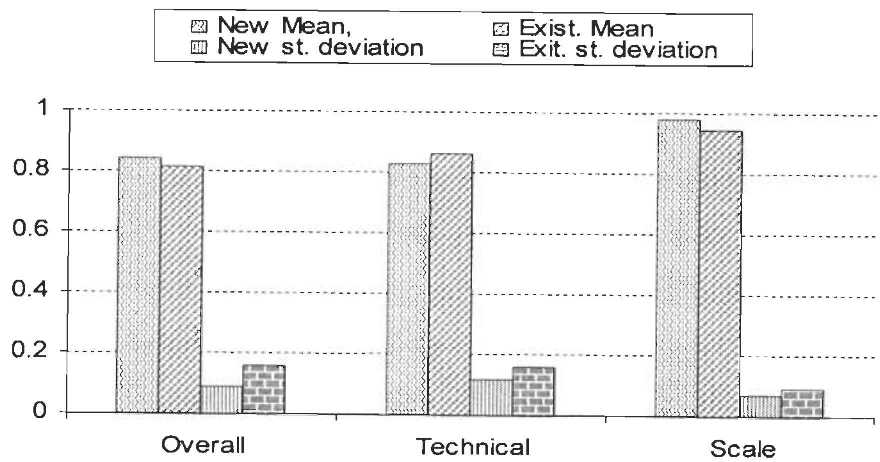


Fig. 5.11: Comparison of mean efficiency scores and their standard deviation

5.7 POLICY IMPLICATION OF THE ANALYTICAL RESULTS

Above DEA analysis reveals that most of the divisions are relatively inefficient and slack analysis identifies the scope for possible reduction in O&M cost and number of employees. Table 5.4 demonstrate the need for induction of cost efficiency among the divisions in the power supply services owned by UPCL; as per the result, it is possible to reduce ` 5.909 Million yearly, invoking higher efficiency in the current practices of UPCL. This may yield cash surplus sufficient enough to improve services to the customers, and to extend the service to the potential customers. It is worth mentioning that, in Uttarakhand access to power still remains a cherished goal i.e. power to all which is to be achieved by the year 2012. Only 53% of the house holds have been electrified so far [119].

However, if 100% electrification is achieved, and even the geographically remote regions are covered, it is likely that the cost incurred on providing power to all will show an upward trend, which may slightly vary from division to division. It implies that, progressive accessibility to electricity is likely to pose considerable challenge to the performance of all divisions over the next few years. It confers that; there is a distinct opportunity of significant savings through efficiency improvements. O&M cost constitutes of three major controllable components that are Employee's costs, Repairing and Maintenance (R&M) costs, and Administrative and General (A&G) costs. Since in this analysis number of employees has been also taken as an input, therefore employees costs are excluded from the O&M cost.

The major constituent of the R&M costs are plant and machinery, buildings and civil works, lines and cable networks, vehicles, furniture & fixtures, office equipments. Some of the measures that may be adopted for the reduction of this cost components could be [83]:

- Specific Renovation and Maintenance program.
- Adoption of better maintenance practices.
- Access to Reliability Centered Maintenance (RCM) approach will provide utilities with a structured way to a maintenance program with an optimum balance between cost of maintenance and reliability improvement.

In addition, application of inexpensive sensor techniques and effective diagnostics to maintain equipment's health, data coordination from multiple sources for analysis and decision making and experienced pool of trained professionals will help in reducing R&M cost component.

A&G expenses constitutes rent, rates, taxes, insurance, telephone, postage & telegrams, legal and professional charges, audit fees, fees and subscriptions, conveyance & traveling, electricity & water charges, printing and stationary, advertisement & promotion. A major chunk of these expenses can be mitigated by keeping updated with the advancement in the field of information technology. Thus, it is necessary to periodically review and update the maintenance program using a structured method.

The slack in terms of number of employees reveals the extent of inefficiencies prevalent with respect to the overstaffing in UPCL. Theoretically, there is a potential of curtailment 435 employees at various division level, constituting approximately 10% of the total current staff strength in all division. It must be pointed out here that the actual potential of staff in real condition might be lesser, since the present model may not have captured the entire variable. Further more, ground realities such as the expansion of electrification accessibility in view of the government aim to provide "power for all" by the year 2012 may actually result in higher requirement of staff and in restricting curtailment of employed staff. However, UPCL have taken corrective measures towards this problem through stopping the further recruitment of some categories of the fourth grade employees and these employees are employed on the contract basis as per need.

The manager can not augment the number of employees with ease, considering the political interference and monopolistic nature of electricity market, it is suggested that divisions should explore this area in order to enhance performance. Motivation of the work force and optimal utilization of the skill can be achieved through empowerment by establishing an effective reward mechanism and competition among divisions for efficient operation. The effectiveness of operations management also involves the accuracy of system operation, keeping pace with advancement of information technology, effectiveness of internal audit system which may not achieved by general aptitudes and trades. The specialized aptitudes and trades can be successfully learned to a variety of procedural and meta- cognitive training.

5.8 CONCLUDING REMARKS

Using DEA, the paper explores the relative performance of 29 EDDs of Uttarakhand- an Indian state. The use of DEA for evaluating the relative efficiencies of Electricity Distribution Divisions provided an insight of the micro level issues in the context of resource utilization. CCR and BCC model were applied to evaluate the overall efficiency, technical efficiency and scale efficiency of divisions. Results reveal that only 8 divisions are identified as overall efficient and EDDs located in plain region outperform those located in hilly region. Most of the divisions are inefficient because of inappropriate scale size i.e. they are not operating at optimal scale. Findings of the slack analysis provided possible improvement directions for inefficient divisions. It highlighted the fact that, three divisions are required to focus on controlling their O&M expenses while overstaffing is found to be associated with 10 divisions. Sensitivity analysis further helped in identifying the specific areas to be considered for efficiency enhancement. Reliability analysis of the CCR frontier divisions gives the robustness of the efficiency result. Most of the inefficient divisions suffered from scale inefficiency to a greater degree than technical inefficiency. Based on the result of BCC analysis, a restructuring algorithm is proposed. The proposed algorithm curved out six new EDDs from the scale inefficient existing EDDs. The algorithm is verified by comparing the mean efficiency of the set of EDDs derived using the proposed algorithm with that of existing set of EDDs. The result indicated that the mean efficiency of the EDDs slightly increased when six new EDDs were created using proposed algorithm. Hence, using the proposed model of reorganization, the decreasing trend of mean efficiency of EDDs due to restructuring, as observed for the period of analysis, can be reversed.

Chapter 6

HOLISTIC APPROACH MODEL FOR REALISTIC GOAL SETTING FOR EFFICIENCY ENHANCEMENT WITH AN APPLICATION TO INDIAN POWER SECTOR

6.1 INTRODUCTION

One of the greatest challenges faced by developing nations in the scenario of ever increasing energy demand is to operate and manage their power utilities in efficient and economic way [173]. In recent years, the power industry privatization and restructuring are gaining international importance as a measure to achieve this. Efficiency measurement is a time tested and integral part of power and energy sector for many years. Various research reports on organizational performances have forced the decision makers to be more concerned about finding ways to improve productivity. DEA has been established as one of the most advanced methodology and practicable approach for evaluating relative efficiency of homogenous decision making units (DMUs). Presently DEA has grown to be an indispensable tool in the areas of operations research and management science [88, 179].

While DEA has proved to be an effective approach in identifying the best practice frontier, its flexibility in weighting multiple inputs and outputs and its nature of self evaluation have been seen with skepticism [150, 166]. To overcome this shortfall, cross evaluation method was developed by Sexton *et al.* [160] and was later examined in detail by [67, 68] as a DEA extension tool. It can be utilized to identify best performing DMUs and to rank DMUs using cross-efficiency scores that are linked to all DMUs [87, 160]. The two principle advantages of cross evaluation are firstly it provides a unique ordering of the DMUs and secondly, it eliminates unrealistic weighting scheme without requiring the elicitation of weight restrictions from application area experts [159]. This chapter re-evaluates the results of analysis based on simple radial efficiency with the introduction of cross-efficiency measures in DEA to bring forth the true performance of 29 EDDs of Uttarakhand in the year 2007-08 [174]. This research work differentiates the true "overall efficient" divisions from "false positive" divisions which can be termed as apparent efficient divisions. Further cluster analysis is used for selecting more appropriate targets to be used as a benchmark by the poorly performing divisions. A benchmark-share measure is also developed for technically efficient EDDs in order to further characterize the performance of efficient ones [29, 78] and to yield information on the role of each efficient division played in benchmarking inefficient divisions and also to identify the best EDDs in terms of the benchmark-share.

6.2 METHODOLOGY

6.2.1 Cross Efficiency Evaluation

A general input minimization Charnes, Cooper and Rhodes (CCR) DEA model can be represented by Eq. (4.2).

Solving Eq. (4.2) by using LINDO version 6.1 software, the optimal multiplier weights can be allocated for each DMU, denoted as $v_r^* = \left(v_{1j}^*, v_{2j}^*, \ldots, v_{sj}^*\right)$, $u_i^* = \left(u_{1j}^*, u_{2j}^*, \ldots, u_{mj}^*\right)$, where $j = 1, \ldots, n$ which guarantees the j^{th} DMU with the maximum efficiency value.

As one weighting scheme can be favorable to a DMU and unfavorable to the others, we can obtain the cross-efficiency to vary in calculating the efficiency with other DMUs optimal weights. We define the formula as follows:

$$E_{po} = \frac{\sum_{r=1}^{s} v_{rp}^* y_{ro}}{\sum_{i=1}^{m} u_{ip}^* x_{io}} \qquad \ldots(6.1)$$

E_{po} denotes the cross efficiency of DMU_o using the weighting scheme of DMU_p. Thus, E_{oo} would be the efficiency score for DMU_o using its own weighting scheme, which is the efficiency score given by the CRS multiplier model.

Table 6.1: Cross-efficiency matrix

	DMU_1	DMU_2	DMU_3	...	DMU_n
DMU_1	E_{11}	E_{12}	E_{13}	...	E_{1n}
DMU_2	E_{21}	E_{22}	E_{23}	...	E_{2n}
DMU_3	E_{31}	E_{32}	E_{33}	...	E_{3n}
...	...	...	...	...	...
DMU_n	E_{n1}	E_{n2}	E_{n3}	...	E_{nn}
Cross efficiency	e_1	e_2	e_3		e_n

After the weighting scheme and cross efficiency has been found, the Cross Efficiency Matrix (CEM) is derived by the algorithm proposed by Doyle and Green [67] as shown in Table 6.1. Using this matrix the mean cross efficiency of the DMU_o is calculated by solving the following equation:

$$e_o = \frac{1}{n}\left(\sum_{p=1}^{n} E_{po}\right) \qquad \ldots(6.2)$$

The column means of the CEM are computed to discriminate between the overall efficient and false positive DMUs.

6.2.2 Calculation of False Positive Indices

False Positive Index (FPI) is calculated to quantify the deviation of the overall efficiency from cross efficiency. The FPI relates to the percentage increment in efficiency that a DMU achieves when moving from peer appraisal to self appraisal. This FPI is similar to the "maverick" index suggested by Doyle and Green [67]. It is calculated by solving the following equation:

$$FPI_o = \frac{E_{oo} - \frac{1}{n}\left(\sum_{p=1}^{n} E_{po}\right)}{\frac{1}{n}\left(\sum_{p=1}^{n} E_{po}\right)} \qquad \ldots(6.3)$$

where E_{oo} is the simple (CCR) efficiency of DMU_o, E_{po} is the cross efficiency score of DMU_o evaluated with DMU_p weights and $\frac{1}{n}\left(\sum_{p=1}^{n} E_{po}\right)$ is the mean score of DMU_o obtained from the CEM.

6.2.3 Benchmark-Share Measure

The technical efficiency of each EDD can be computed as a solution to the linear programming (LP) problem as given by Eq. (5.2).

Role played by the efficient DMU as a benchmark for the inefficient ones is of interest. One may want to know the importance of each efficient DMU in measuring the extent of inefficiencies of inefficient DMUs. One way to accomplish such a task is to count the number of times a particular efficient unit acts as referent DMU [124]. On the other hand, Andersen and Petersen [114] rank the efficient DMUs by measuring the radial distance from a specific efficient DMU to a frontier constructed by the remaining DMUs. The most efficient (or important) DMU is the one that has the largest radial distance.

However, it is possible that the efficient DMU detected by Andersen and Petersen method may never appear in the reference set for inefficient DMUs. Torgersen *et al.* [13] define a ranking measure by using lambda values in the VRS model. Zhu [78] and Yang and Lu [29] presented ranking measure through benchmark share measure. For ranking the efficient units Tone [85] proposed a super efficiency model by using slack based measure (SBM).

Here, for a particular inefficient EDD_d the factor specific (k^{th} input specific and q^{th} output specific) measure is determined through the following two linear programming problems solved by Lindo [93] and the existing BCC model's best practice frontier (derived by Eq. 5.2).

The k^{th} input-specific DEA model is given as:

$$\begin{aligned} & \theta_d^{k*} = \min\ \theta_d^k, && d \in N \\ \text{s.t.}\quad & \sum_{j\in E} \lambda_j^d x_{kj} = \theta_d^k x_{kd}, && k \in \{1,\dots,m\} \\ & \sum_{j\in E} \lambda_j^d x_{ij} \le x_{id}, && i \neq k \\ & \sum_{j\in E} \lambda_j^d y_{rj} \ge y_{rd}, && r = 1,\dots,s \\ & \sum_{j\in E} \lambda_j^d = 1 \\ & \theta_d^k, \lambda_j^d \ge 0,\ j \in E. \end{aligned} \qquad \dots(6.4)$$

The q^{th} output-specific DEA model is given as:

$$\begin{aligned} & \phi_d^{q*} = \max\ \phi_d^q, && d \in N \\ \text{s.t.}\quad & \sum_{j\in E} \lambda_j^d y_{qj} = \phi_d^q y_{qd}, && q \in \{1,\dots,s\} \\ & \sum_{j\in E} \lambda_j^d y_{rj} \ge y_{rd}, && r \neq q \\ & \sum_{j\in E} \lambda_j^d x_{ij} \le x_{id}, && i = 1,\dots,m \\ & \sum_{j\in E} \lambda_j^d = 1 \\ & \phi_d^q, \lambda_j^d \ge 0,\ j \in E. \end{aligned} \qquad \dots(6.5)$$

Here, E and N, respectively, represent the index sets for the efficient and inefficient EDDs identified by BCC model (Eq. 5.2). The factor specific measure in Eq. (6.4) and (6.5) determine the maximum potential decrease of an input and increase of an output respectively while keeping other inputs and outputs at current levels. These factor-specific measures are multi-factor performance measures, since all concerned factors are considered in a single model.

The k^{th} input-specific benchmark-share measure for each efficient EDD is measured by the following equation, where $j \in E$ is

$$\Delta_j^k = \frac{\sum_{d \in N} \lambda_j^{d*}\left(1-\theta_d^{k*}\right)x_{kd}}{\sum_{d \in N}\left(1-\theta_d^{k*}\right)x_{kd}} \qquad \ldots(6.6)$$

where λ_j^{d*} and θ_d^{k*} are optimal values in Eq. (6.4).

The q^{th} output-specific benchmark-share measure for each efficient EDD is calculated by using 6.7, where $j \in E$, is

$$\Pi_j^q = \frac{\sum_{d \in N} \lambda_j^{d*}\left[1-\left(\frac{1}{\phi_d^{q*}}\right)\right]y_{qd}}{\sum_{d \in N}\left[1-\left(\frac{1}{\phi_d^{q*}}\right)\right]y_{qd}} \qquad \ldots(6.7)$$

where λ_j^{d*} and ϕ^{q*}_d are optimal values in Eq. (6.5).

The benchmark-share Δ_j^k (or Π_j^q) depends on the values of λ_j^{d*} and θ_d^{k*} (or λ_j^{d*} and ϕ_d^{k*}). Note that $(1-\theta_d^{k*})x_{kd}$ and $\left[1-(1/\phi_q^{d*})\right]y_{qd}$ identifies the potential decrease on the k^{th} input and increase on the q^{th} output, respectively. Therefore, the benchmark-share here measures the contribution that efficient EDDs makes to the potential input (output) enhancement in inefficient EDDs.

Terms Δ_j^k and Π_j^q are weighted optimal lambda values across all inefficient EDDs. The weights:

$$\left[\frac{(1-\theta_d^{k*})x_{kd}}{\sum_{d \in N}(1-\theta_d^{k*})x_{kd}}\right] \text{ and } \left\{\frac{\left[1-\left(\frac{1}{\phi_d^{k*}}\right)\right]y_{qd}}{\sum_{d \in N}\left[1-\left(\frac{1}{\phi_d^{k*}}\right)\right]y_{qd}}\right\}$$

are normalized, and therefore, we have $\sum_{j \in E}\Delta_j^k = 1$ and $\sum_{j \in E}\Pi_j^q = 1$. It can be observed from 6.6 and 6.7 that an efficient EDD that does not act as a benchmark EDD for any inefficient EDD will have a zero benchmark-share measure. The larger value of benchmark-share measure indicates that an efficient EDD is more important in benchmarking.

6.3 INPUT OUTPUT SELECTION

Selection of input and output is based on the same approach as discussed in Chapter 4 and Chapter 5.

Inputs:

x_1 : **Operating and Maintenance (O & M) cost** (` Million)

x_2 : **Number of employees**

Outputs:

y_1 : **Energy sold** (Million Units)

y_2 : **Number of customers**

y_3 : **Average duration of interruption** (Hours)

y_4 : **Distribution line length** (Circuit kilometer)

y_5 : **Transformer capacity** (kVA)

6.4 RESULTS AND DISCUSSION

6.4.1 Cross Efficiency Evaluation

In this study the dual linear programming formulation of the CCR models were applied for the year 2007-08 to calculate the overall efficiency. In the CCR model 27.58% of the DMUs are found to be overall efficient. The major short coming of this traditional model is that, the efficient divisions can not be ranked according to their level of efficiency. To achieve this, further analysis is carried out based on peer appraisal model. In this model each DMU is evaluated according to the optimal weighting scheme of other DMUs. The optimal weights are obtained using Eq. (4.2), which is solved in the present work using LP Solver Lindo version 6.1 [93] and a CEM of an order of 29×29 is evaluated. The CCR efficiency and mean cross-efficiency scores are represented in Table 6.2. CCR result identifies 8 electric distribution divisions as efficient ones.

Table 6.2 indicates that mean cross efficiency of CCR efficient DMUs varies from 68% to 100%. Haridwar (R) has highest mean cross- efficiency score of 100%, hence rated as the division with best overall practices, in comparison to other divisions. The CCR inefficient division Vikasnagar with mean cross efficiency 73% ranked eighth in the entire set and is identified as better overall practices than Haridwar (U), CCR efficient division. Division Haridwar (U) having CCR efficiency score of 100% comes out to be a strong "false positive" with a low mean cross efficiency score of 68.2% and hence ranked 10th in the entire set.

Table 6.2: Overall efficiency, cross efficiency and false positive index of the EDDs

S. No.	Circle/EDDs	CCR Efficiency	Cross Efficiency		FPI (%)	Geographical Terrain
	EDC (R) Dehradun					
1	Dehradun (R)	1.000	0.913	(2)	9.52	Plain
2	Vikasnagar	0.884	0.730	(8)	21.09	Semi plain
3	Rishikesh	0.817	0.598	(15)	36.62	Semi plain
4	Uttarkashi	0.598	0.485	(24)	23.29	Hilly
	EDC (U) Dehradun					
5	Dehradun (N)	0.511	0.383	(28)	33.42	Semi plain
6	Dehradun (S)	0.670	0.496	(23)	35.08	Plain
7	Dehradun (C)	0.725	0.398	(26)	82.16	Plain
	EDC Srinagar					
8	Srinagar	0.948	0.656	(12)	44.51	Hilly
9	Tehri	0.753	0.623	(14)	20.86	Hilly
10	Gopeswar	0.737	0.589	(16)	25.12	Hilly
11	Kotdwar	0.829	0.716	(19)	15.78	Semi plain
12	Rudraprayag	0.712	0.588	(17)	21.08	Hilly
	EDC Roorkee					
13	Roorkee (U)	0.967	0.682	(11)	41.78	Plain
14	Roorkee (R)	1.000	0.752	(7)	32.97	Plain
15	Haridwar (U)	1.000	0.683	(10)	46.62	Plain
16	Haridwar (R)	1.000	1.000	(1)	0.000	Plain
	EDC Haldwani					
17	Nainital	0.772	0.578	(19)	33.56	Hilly
18	Ramnagar	0.522	0.390	(27)	33.84	Semi plain
19	Haldwani (U)	0.541	0.316	(29)	71.20	Plain
20	Haldwani (R)	0.650	0.441	(25)	47.39	Semi plain
	EDC Rudrapur					
21	Kashipur	1.000	0.757	(6)	32.100	Plain
22	Bazpur	1.000	0.770	(5)	29.870	Plain
23	Rudrapur	1.000	0.779	(4)	28.36	Plain
24	Sitarganj	1.000	0.785	(3)	27.380	Plain
	EDC Ranikhet					
25	Ranikhet	0.755	0.580	(18)	30.17	Hilly
26	Almora	0.892	0.549	(21)	62.47	Hilly
27	Bageswar	0.673	0.523	(22)	28.68	Hilly
28	Pithoragarh	0.749	0.563	(20)	33.03	Hilly
29	Champawat	0.843	0.642	(13)	31.300	Hilly

Numerical values in the parenthesis give the ranking of the divisions

It can be observed from Table 6.2 that plain area divisions are dominating and have achieved relatively higher rank than the hilly divisions. The FPI values mentioned against each division indicate the accuracy of the CCR results. A lower value of FPI indicates lesser deviation of cross efficiency from CCR efficiency. A highly false positive division has the characteristics of weighting heavily on a single input or output, thus making it more efficient as compared to other divisions. The false positive index presented in Table 6.2, clearly indicate that Dehradun (C) division achieve a 82.16% increase in efficiency when shifting from peer appraisal to self appraisal. Thus, it can be considered to be a strong false positive division. The result also provides important information by identifying those divisions that are enjoying the largest and smallest benefits when moving from peer appraisal to self appraisal. Management must avoid divisions for implementing efficiency improvement measures; those have large FPI values, even if they have high CCR efficiency. Moreover, it is often difficult to improve the performance of highly false positive divisions because they may require improvement in many dimensions. From managerial point of view, it may be easier to improve a division with lower CCR efficiency and with a low FPI rather than a division with higher CCR efficiency and with a high FPI. It is important to note that a DMU with a simple radial efficiency score of one is not always in best overall practices. In Fig. 6.1 overall efficiency and mean cross efficiency of all the divisions are juxtaposed, and also their respective false positive indexes are plotted for each EDD.

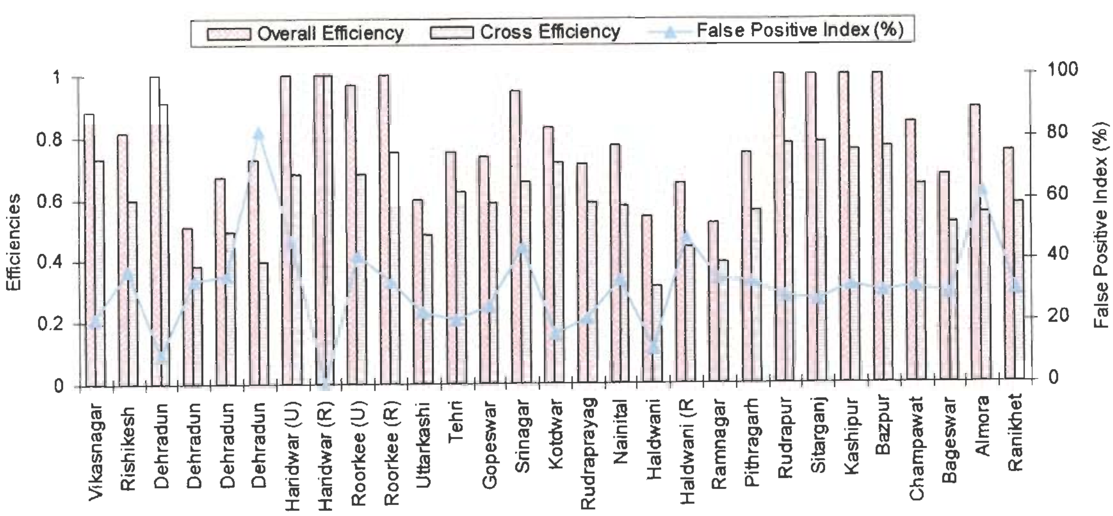


Fig. 6.1: Comparison of overall efficiency, cross efficiency and false positive index

It is important for the resource managers to determine the relative importance of each input to the measured efficiency. This data is instrumental to establish, why management should be given greater flexibility in the use of a particular input variable. The magnitude of $(v_m x_{mj})/(\sum_{m=1}^{2} v_m x_{mj})$ [166] can be estimated for each inputs (m = 1, 2) and each divisions (j = 1, 2..., 29), where v_m are the weights associated with each input. Further, the averaged percentage values of each input for plain, semi plain and hilly divisions can also be calculated. Results of the average estimated weights of inputs of the plain EDDs show that number of employees is relatively more important input (58.8%) than O&M cost (41.2%). For the semi plain divisions both inputs are of equal importance (51.38% each). As far as the hilly divisions are concerned, O&M cost is more important input (63.63%) as compared to number of employees (36.36%).

It is found that number of employees of plain divisions predominantly contributes to the measured efficiency. This implies that inefficient divisions can effectively promote resource utilization efficiency, rather than by varying the number of employees directly. As the manager cannot augment the number of employees with ease, considering the political interference and monopolistic nature of the electricity market, it is suggested that divisions should explore this area in order to enhance their performances. Human resource management involves motivating the work force and optimal utilization of the skill they have. It can be achieved through personal empowerment by establishing an effective reward mechanism. Management effort as has the scope to achieve corporate success through adequate training of the work force, establishing effective performance evaluation mechanism and feedback system. The promotion of labor productivity also has great bearing on effectiveness of hiring process. The effectiveness of operations management also involves the accuracy of system operation, keeping pace with the advancement of information technology, effectiveness of internal audit system, which is not demonstrated by general aptitudes and trades. These aptitudes and trades can be successfully learned through a variety of procedural and meta-cognitive training. Some skills are learned, and this learning could be developed such a way that managers build up environment conducive for learning. In a learning organization, staff are always enquiring into the systematic consequences of their actions, rather than just focusing on local consequences.

Besides this, it is also found that for hilly divisions, O&M cost input can play important role in efficiency improvement. Thus hilly distributors can enhance their efficiency by reducing the operating and maintenance cost, which the manager can relatively control with ease. Similarly inefficient semi plane divisions could improve their efficiency by adopting both the ways mentioned above.

6.4.2 Clustering of EDDs

This section involves the identification of benchmark EDDs that can be used by poorly performing divisions as a platform for the efficiency improvement. A difficulty with a linear combination of DMUs as the reference set in DEA is that, an inefficient DMU and its reference set may not be inherently similar in their practices [67]. Therefore, it is possible that in some cases the reference targets may be unattainable goals for the inefficient DMUs. Thus, alternatively cluster analysis, principle components and multidimensional scaling is used to classify DMUs more accurately into similar groups or clusters.

In the present work hierarchical clustering approach is adopted to effectively group similar distribution divisions, this technique can herald realistic targets for poorly performing EDDs to improve. In this method Pearson correlation coefficient between pairs of column in a CEM is calculated. This parameter describes the degree of similarity in the EDDs and hence using these correlation coefficients as the elements in a resemblance matrix and thereafter executing a clustering analysis using complete linkage method yields different clusters of divisions with similar practices [128]. Divisions with the highest column mean in a cluster can be used as the primary benchmark for the other EDDs in that cluster. The tree is truncated after obtaining a reasonable level of clustering among the divisions.

Fig. 6.2 illustrates the eight clusters that are identified from the above method. Among eight clusters forming the tree, cluster C-6 consist of EDDs with high false positive index and do not have any divisions with high mean scores. Thus for improvement, it is difficult to find a good "model" for these divisions as they are inherently different from "overall" efficient divisions and require improvements in a number of dimensions. However, divisions in these clusters may use other efficient divisions from adjacent clusters as secondary benchmarks. Division 14 though has high column mean and simple radial efficiency but is the sole constituent of cluster 8, hence will not be a realistic primary benchmark for others. C-1 and C-4 generally are combinations of divisions with high mean cross efficiency. The highest mean score for C-4 is obtained for division 16. The rest of the divisions should mark the operating characteristics of division 16 and can improve their performance either by decreasing inputs or increasing outputs.

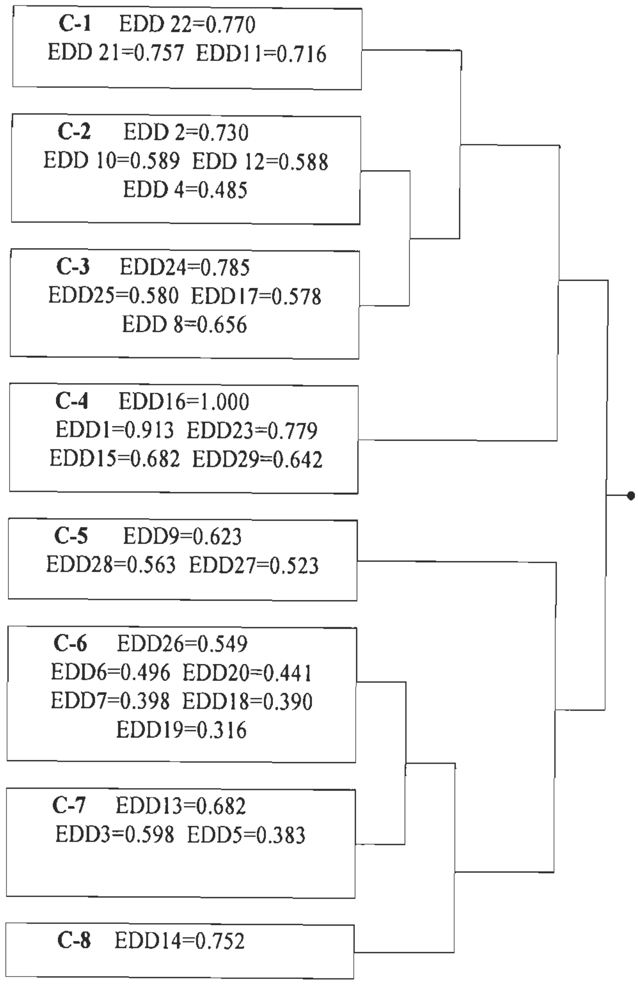


Fig. 6.2: Clusters of divisions

This analysis will provide realistic targets for the resource managers of the inefficient EDDs, which can be used as a benchmark in order to make them more efficient and productive. It is also illustrated that mere overall efficiency, calculated solely from CCR model is not an adequate measure for differentiating the divisions based on their performance rather a clustering approach based on a CEM, can effectively differentiate a realistic subset of features and provide practically achievable strategic targets for performance enhancement.

Table 6.3: Benchmark share for technically efficient EDDs

EDDs	Input factors		Output factors					Average Rank
	x_1	x_2	y_1	y_2	y_3	y_4	y_5	
Haridwar (R)	51.00% (1)	44.82% (1)	3.01% (8)	8.37% (5)	23.39% (2)	24.89% (2)	15.01% (2)	3
Dehradun (R)	7.88% (4)	20.57% (2)	3.94% (6)	12.39% (3)	3.86% (5)	53.06% (1)	6.98% (6)	3.8
Srinagar	10.17% (3)	0.00%(11.5)	3.20% (7)	9.91% (4)	3.22% (6)	9.17% (3)	13.98% (3)	5.36
Roorkee (U)	16.18% (2)	7.41% (4)	0.00% (12)	42.86% (1)	17.08% (4)	0.01% (10)	4.82% (5)	5.43
Roorkee (R)	0.94% (8)	2.88% (6)	1.12% (10)	1.86% (7)	30.63 (1)	2.31% (5)	51.15% (1)	5.43
Kashipur	0.91% (9)	0.00%(11.5)	25.15% (2)	0.53% (8)	18.91% (3)	2.21% (6)	2.27% (8)	6.78
Bazpur	2.06% (7)	2.97% (5)	25.61% (1)	0.00% (11.5)	0.80% (9)	4.90% (4)	0.00% (11.5)	7.00
Sitarganj	0.00% (11.5)	18.46% (3)	9.32% (4)	15.72% (2)	0.00%(11.5)	0.00% (12)	0.00% (11.5)	7.93
Rudrapur	3.34% (6)	0.59% (9)	21.33% (3)	0.00% (11.5)	0.00%(11.5)	2.02% (7)	0.00% (11.5)	8.5
Kotdwar	0.00% (11.5)	0.80% (8)	2.30% (9)	8.27% (6)	0.89% (8)	0.00% (12)	2.43% (7)	8.78
Haridwar (U)	7.52% (5)	0.00%(11.5)	5.02% (5)	0.00% (11.5)	0.00%(11.5)	0.00% (12)	0.00% (11.5)	9.71
Tehri	0% (11.5)	0.00%(11.5)	0.00% (12)	0.09% (9)	1.22% (7)	1.28% (8)	0.75% (9)	9.71
Pithoragarh	0% (11.5)	1.50% (7)	0.00% (12)	0.00% (11.5)	0.00%(11.5)	0.15% (9)	2.62% (6)	9.78
Sum	100%	100%	100%	100%	100%	100%	100%	

6.4.3 Benchmark Share Measure for the BCC Formulation

Efficient DMUs are designated as benchmarks for inefficient DMUs. Inefficient DMUs can try to emulate their benchmarks for efficiency enhancement [141].

The benchmark share measure is developed for each frontier division in order to further characterize the performance of technically efficient divisions. Table 6.3 summaries the benchmark share for the technically efficient EDDs, with the ranking mentioned in parenthesis and ordered by the average rank of the efficient units. This analysis gives the ranking list of the performance model for all the 13 technically efficient EDDs (Table 5.6). With this we can now identify the inputs and outputs that are most influential in increasing the efficiency; also those divisions can be now zeroed upon with ease, which is to be treated as benchmarks, looking at the average ranking.

Technically efficient division Haridwar (R) has highest share measure in both the inputs; O&M cost (x_1) and Number of employees (x_2). Roorkee (R) has a leading role in terms of Transformer capacity (y_5) and duration of interruptions per feeder (y_3). As far as distribution line length (y_4) is concerned Dehradun (R) contributed highest share as a benchmark for other inefficient divisions. Whereas divisions Roorkee (U) and Bazpur occupy the first rank in terms benchmark share for outputs number of customers (y_2) and energy sold (y_1) respectively.

All the above stated EDDs with highest share measure are overall efficient except Roorkee (U) with 96.7%. Thus, it can be said that EDDs that are technically as well as scale efficient have highest benchmark share in input and output factors for inefficient ones. The bigger the benchmark share, the more important an efficient division is in benchmarking. Divisions like Kotdwar, Haridwar (U), Tehri and Pithoragarh are poorly benchmarked by inefficient EDDs with benchmark share below 10% and for most of the inputs and outputs it is 0%. Though these EDDs are efficient, they reveal to be too different in the input output space to be referenced by the inefficient ones and they are termed as self evaluators. It can also be noticed from the Table 6.3 that plain area divisions are dominating in the benchmark share and hold relatively higher average rank. This indicates that these divisions are close in input/output space to the inefficient ones, i.e. efficiently producing a similar product-mix using a similar mix of resources. Hilly divisions Tehri and Pithoragarh occupy the lowest rank in the average rank list. This result is quite pragmatic since scale of various inputs, is more easily attainable for plain EDDs while it is relatively more difficult to imitate the scale of hilly efficient EDDs. Exception is there with Srinagar though belonging to hilly area is at third rank, but it does not have highest share measure for any input and output factors. The average ranking of the benchmark share is treated with paramount importance for zeroing on the benchmarks or best-practice-frontier divisions in the present work.

6.5 CONCLUDING REMARKS

DEA have gained popularity among the researchers for analysis of DMUs with multiple inputs and outputs in order to evaluate the performance of any organization. But results of the analysis based on DEA technique are not always accurate and some times contradictory which obfuscates the end user in field implementation. In this chapter a holistic approach is adopted to scrutinize the results of these various statistical analyses in order to make logical and practically attainable goals for the managers and policy makers to implement.

The present work starts with calculating the overall efficiency of 29 EDDs using DEA, CCR model and then the result is re-evaluated by finding out the cross efficiency of these EDDs. CCR formulation identifies more than one division as efficient and therefore, appropriate ranking is not possible. From cross efficiency analysis we can further deduce that some overall performers exist which are not necessarily similar to the highest overall efficiency distribution divisions examined. Average cross efficiency provides unique ordering of the EDDs. It is assumed that plain, semi plain and hilly distribution divisions minimize their costs under a market environment of regional monopoly. The following point supports this assumption: (i) evaluation of overall efficiency and cross efficiency is based on the mechanism of a firm's cost minimization in its production behavior. (ii) Although there is no market competition among these EDDs, since they are all branches of one company, UPCL, they still pursue yardstick competition in terms of in-house operational performance. Therefore, the assumption of cost minimization behavior in our study is applied.

FPI yielded by this analysis brings forth the truly best performers from the list of so called overall efficient divisions. Haridwar(R), Dehradun (R), Sitarganj and Rudrapur are identified as good overall practices with high mean cross efficiency and can be focused by the managers for the implementation. Haridwar (U) is identified as falsely efficient division due to uneven distribution of weights on input and output factors. Thereafter, the EDDs are categorized into eight clusters through complete linkage method, to identify the EDDs of similar nature of practices. It helps to select the divisions that have the potential to serve as the benchmark for the inefficient ones to improve the efficiency. This is seminal for choosing a realistic benchmark, as target set by the EDD of same cluster will be easier to achieve. False standard clusters are identified to avoid wasting too much effort with these distribution divisions.

Ranking of technically efficient EDDs has been drawn using benchmark share measure. Plain area divisions are dominating in the benchmark share and are frequently referenced by inefficient ones. These benchmarks may be referred for performance improvement by the inefficient ones. However, it is suggested that the selection of any EDD as benchmark should be done by considering the average rank attained by each technically efficient EDD in the benchmark share measure analysis. A higher rank evidently demonstrates the higher potential to influence the performance when referenced by the inefficient ones. The findings of this research work can assist managers to improve the operational management of the EDDs of UPCL.

Chapter 7
CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORKS

7.1 GENERAL

Reform has transformed the institutional framework, organizational structure, and operating environment of the electricity sector in many developed and developing countries from the late 1980s. Although approaches might have varied across the countries, the main motive behind this was to improve the efficiency of the sector. The main features of power sector reforms is the market orientation of their approaches to achieve the efficiency objective by inducing discipline in the product and capital markets to achieve allocative and internal efficiency through competition, privatization, and innovative and effective pricing mechanism.

The dissertation work involved development of a framework for investigating performances of power utilities in India. The work explored the need for measurement of performances in the context of the reforms initiated by the government of India, reviewed the status of electric supplies in India, and identified the linkage of various issues to performances. The conclusions pertaining to these and the future scope for each have been outlined subsequently.

7.2 SUMMARY OF THE SIGNIFICANT FINDINGS

The research work undertaken in the thesis is initiated by developing an understanding of the ongoing restructuring process around the world and in India over the last two decades. Electric supplies become critical and vital in the current context of introduction of reforms in the electricity sector of a rapidly expanding Indian economy. The initial phase of reforms in the Indian power sector was primarily aimed at bringing regulatory reforms and unbundling of the vertically integrated State Electricity Boards (SEBs). Enactment of the Electricity Act, 2003 led to deepening of the reform process by dismantling this monopoly in the power sector. Primary issues emerging on account of transition from a single-buyer model to a multi-buyer multi-seller model include, among others, policy and regulatory initiatives related to open access, power exchanges, and transmission allocation and its pricing. Distribution sector represents the core issue in the entire gamut of reforms in the electricity sector. The shift of focus towards distribution sector is a natural corollary to the efforts at making the sector financially viable. The fundamental goal of distribution reforms is the creation of a structure that encourages competition for fostering efficiencies. Benchmarking distribution utilities is especially crucial and significant currently as the important features of the sector (like tariff policy) are being redesigned in the ongoing reform process. With the liberal market attitude brought about by the introduction of Electricity Act, 2003, unbundling and restructuring is going to be the preferred choice, and to make this process effective, there is an urgent need to carry out scientific analysis of efficiency evaluation for the emerging structure of the distribution sector in India. Data Envelopment Analysis (DEA) is one of the best methods that have been used extensively for benchmarking since its introduction. Applications of DEA were few and sparse in the 1980s; however, from 1990s we see an explosion of application of DEA.

The concept of measuring efficiencies in the delivery of power services has been historically alien in the Indian context, and it is now increasingly being realized that efficiency evaluation is an integral component of any comprehensive reforms program. Such appraisals can form the basis for sector regulation and can help to generate significant internal resources by improvement of performances. DEA is applied in the present work to evaluate the relative efficiency of Electricity Distribution Divisions (EDDs) of Uttarakhand Power Corporation limited (UPCL) for the period 2005-2008. The study brings out that, although the state electricity board disintegrated several EDDs to smaller ones to enhance the overall productivity, but in contrary, the average efficiency of the EDDs de facto dropped in the considered period. Therefore, while adjusting the production scale that possibly leads to progressive production technologies, greater attention should be paid to short-term managerial effort and operational adjustment. Without incorporating proper and effective short-term management, relative operational efficiency will decrease, damaging the total productivity improvement even when long-term strategic directions are correct. The results of Malmquist productivity index based on TFP revealed slight progressive development from 2005-08. On an average the TFP growth during period under observation found to be 2% per year. This indicates that overall productivity of EDDs had improved, and the ongoing reforms were partly successful, in that, a greater change was witnessed on the technology front, a factor might have been propelled by increasing investments made during the above years. Technical regress occurs mainly due to the existing organization structure and lack of competition among divisions. The results also reveal the fact that the distribution divisions were unable to sustain growths on a year-to-year basis.

To scrutinize the ineffectiveness of restructuring process, performance of EDDs for the year 2007 is examined in terms of overall efficiency, technical efficiency and scale efficiency. Slack analysis identifies the scope for possible reduction in input uses. As per the result of slack, divisions can possibly cut off their O&M expenses by ₹ 5.909 Millions yearly, invoking higher efficiency in the current practice of UPCL. This may yield cash surplus sufficient enough to improve services to the customers, and to extend the service to the potential customers. The results of the study also indicate the possibility of achieving significant savings through retrenchment of excessive levels of man power. Theoretically, there is a potential of curtailment 435 number of employees at various division level, constituting approximately 10% of the total current staff strength in all division.

DEA analysis identified several divisions technically as well as scale inefficient. The low value of scale efficiency implies that these divisions have considerable scope for improvements in their efficiencies by resizing their scales of operations to the optimal scale defined by best practice utilities in the sample. Thus, one way to adjust the unbalanced scales of operation is reorganization of the existing EDDs. Based on the result of VRS model, a reorganization algorithm is proposed. Six new divisions are formed from the scale inefficient existing divisions via proposed reorganization algorithm. The result analysis is verified by comparing the mean efficiency of the set of EDDs derived using the proposed algorithm with that of existing set of EDDs. The result indicated that the mean efficiency of the EDDs slightly increased with the formation of six new EDDs. The sensitivity-based classification can be effectively utilized by the policy makers for identifying utilities, where maximum attention must be paid for fostering improvement. The analysis reveals that a wide majority of the distribution divisions are distinctly efficient and for efficiency enhancement it needs immediate attention of the policy makers/regulators. Micro level studies of these utilities are likely to reveal the exact reasons behind such large inefficiencies.

Thereafter, the result is re-evaluated by finding out the cross efficiency of these EDDs. CCR formulation identifies more than one division as efficient and therefore, appropriate ranking is not possible. From cross efficiency analysis we can further deduce that some overall performers exist which are not necessarily similar to the highest overall efficiency distribution divisions examined. FPI yielded by this analysis brings forth the truly best performers from the list of so called overall efficient divisions. Haridwar (R), Dehradun (R), Sitarganj and Rudrapur are identified as good overall practices with high mean cross efficiency and can be focused by the managers for the implementation. Based on the cross efficiency similar practice divisions are grouped into eight clusters. This clustering approach will provide realistic targets for the resource managers of the inefficient EDDs, which can be used as a benchmark in order to make them more efficient and productive. Benchmark share measure identifies the inputs and outputs that are most influential in increasing the efficiency; also those divisions can be now zeroed upon with ease, which is to be treated as benchmarks, looking at the average ranking. Result reveals that plain areas divisions are dominating in the benchmark share and hold relatively higher average rank, i.e., these divisions are close in input/output space to the inefficient ones. Policy implementation of the result analysis is also discussed. Work undertaken by this dissertation will redefine the view point of the utility planners and DEA may be adopted as an additional tool for planning the power utility reforms.

DEA is highly sensitive to the type as well as number of inputs and outputs. Adding variables does not decrease DEA scores and gives utilities a chance to better explain their inefficiencies. If the model includes too many variables, then every utility may be able to cite at least one of the variables that explain its inefficiencies and as a consequence most utilities would appear efficient or near efficient. Therefore, to make DEA analysis meaningful, it becomes imperative to limit the number of inputs and outputs in a small or mid size sample. In conclusion, it must be said that DEA requires careful execution and its results need careful interpretations. A sensitivity analysis can often help to interpret the results more precisely, and prior knowledge of the limitations of the technique can help avoid exaggerated interpretations. DEA is a powerful diagnostic tool but lacks focus on the goals of individual organizations, which may vary considerably. The ultimate onus of delineating and implementing improvement strategies and policies would invariably lie with the utility administrators, managers, and engineers, who must understand the operations of individual efficient units and emulate these best practices for sustained efficiency improvements.

7.3 FUTURE SCOPE FOR RESEARCH

(1) The present DEA analysis indicates that most distribution utilities in Uttarakhand perform sub-optimally compared to the best practices, and there exists significant scope for effective savings. Microanalysis of utility expenditures at the sub-station wise would yield valuable information on the areas that need to be focused upon in order to harness these savings. Hence, microanalysis of expenditures at selected utilities is likely to yield valuable information for initiating policies for ensuring optimal resource allocation.

(2) Similar microanalysis for other states can also yield valuable information for affecting reductions in operating and maintenance cost and staff deployments. Such studies are likely to yield invaluable outcomes that would be of great significance with regard to evolving policy measures for improvement of electricity distribution utilities, and for its sustenance.

(3) Due to limitation of data availability it was not possible to incorporate parameters like peak demand and population density division wise. It is suggested that, in future, possibly with the improvement of information resource base, models may be developed to incorporate specific aspects of environment.

(4) Other studies that would be useful from a practical perspective could comprise analyses of individual utilities for assessing the scope of mobilizing internal resources through directing and evolving reengineering strategies like implementing innovative methods for reducing T&D losses, better O&M, implementing better network monitoring, and ensuring greater vigilance and action with regard to prevention of unauthorized connections.

(5) It can also be applied for assessing the performance of Electricity Distribution Circle (EDC) of different states and their relative performance can be compared and measures can be drawn for improvement in efficiency.

(6) The efficiency analysis can be extended for establishing the appropriate X-factor based regulation scheme for providing incentives to utilities in line

with the practices being adopted by UK, Norway, Netherlands and Australia.

(7) Studies may be undertaken to benchmark Indian electric utilities using other techniques such as Stochastic Frontier Analysis (SFA) and results may be compared with the current analysis to gain greater insights.

(8) Benchmarking studies may also be undertaken to draw lessons from other developing countries as well as developed countries, and these International best practices may be compared and adopted for the Indian conditions in order to make the Indian electricity sector more efficient.

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PUBLICATIONS FROM THE WORK

(a) International Journals Published / Accepted:

[1] V.K. Yadav; N.P. Padhy and H.O. Gupta "A micro level study of an Indian electric utility for efficiency enhancement" Energy, vol. 35, Issue 10, pp. 4053-4063, 2010, Elsevier.

[2] V.K. Yadav; N.P. Padhy and H.O. Gupta "Evaluation of the efficacy of ongoing reform initiative of an Indian electric utility" Accepted for Publication in Energy Source Part B: Economics, Planning, and Policy, Taylor and Francis (Manuscript ID: UESB-2010-0039).

[3] V.K. Yadav; N.P. Padhy and H.O. Gupta "Holistic approach model for realistic goal setting for efficiency enhancement with application to Indian power sector" Accepted for Publication in Energy Source Part B: Economics, Planning, and Policy, Taylor and Francis (Manuscript ID: UESB-2010-0046. R2).

(b) International Journal Accepted with minor revision

[1] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Introspection of Restructuring Process of An Indian Electric Utility" *International Journal of Energy Technology and Policy*, Inderscience.

(c) International Conferences Published:

[1] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Efficiency Evaluation of Operational and Design of Supply System" *IEEE General Meeting, Minneapolis USA,* July 26, 2010.

[2] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Assessment of Indian power sector reform through Productivity Analysis: Pre and Post Electricity Act, 2003" *IEEE PES, Transmission and Distribution Conference, Ernest N. Morial Convention Center New Orleans, Louisiana,* April 2010.

[3] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Assessing the Performance of Electric Utilities of Developing Countries: An Intercountry Comparison Using DEA" *IEEE General Meeting, Calgary, Alberta, Canada* July 26-30, 2009.

[4] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Efficiency Improvement Directions for Electric Utilities in Developing Countries Using DEA" Proceedings of *International Conference on energy and environment.* ISSN: 2070-3740, March 19-21, 2009.

(d) National Conference Published:

[1] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Performance Evaluation of Indian Electric Utility: An Intercountry Comparison Using DEA" *Fifteenth National Power System Conference (NPSC)*, IIT Bombay, pp 301-304, December 2008.

(e) International Journal Communicated:

[1] Vinod Kumar Yadav, Narayan Prasad Padhy and Hari Om Gupta "Performance Evaluation and Improvement Directions for an Indian Electric Utility" *Energy Policy, Elsevier* (Manuscript Number JEPO-D-10-00775).

Table A.1: Data for the Year 2005-06

S. No.	EDDS/circle	Energy Sold	Number of Customers	Distribution Line Length	Transformer Capacity	O&M Cost	Number of Employees
	EDC (R) Dehradun						
1	Dehradun (R)	176.058	60684	7136.36	1222	31.599	218
2	Rishikesh	123.973	35855	1261	401	5.924	97
3	Uttarkashi	32.117	26050	2177.44	969	12.747	189
	EDC (U) Dehradun						
4	Dehradun (N)	206.716	54180	1421.01	491	10.460	205
5	Dehradun (S)	248.803	65326	2410.85	461	30.329	212
	EDC Srinagar						
6	Srinagar	78.284	49255	3518.16	912	6.453	253
7	Tehri	145.327	37256	4826.2	1635	14.635	230
8	Gopeswar	43.631	41271	3863.42	1146	18.159	252
9	Kotdwar	257.033	44331	4044.57	1336	12.540	215
10	Rudraprayag	17.898	25663	2485.51	779	6.101	145
	EDC Roorkee						
11	Roorkee	353.39	73821	3477.82	4064	10.981	224
12	Haridwar	387.336	69090	2738.98	1858	1.039	229
	EDC Haldwani						
13	Nainital	63.764	29398	3232.94	926	5.146	174
14	Ramnagar	58.052	21215	1090.02	492	4.901	109
15	Haldwani (U)	74.97	27057	308.23	263	5.758	126
16	Haldwani (R)	113.859	25938	877.69	605	0.946	103
	EDC Rudrapur						
17	Kashipur	555.965	53037	2842.35	2078	11.077	298
18	Rudrapur	350.392	78157	4202.98	2640	11.968	228

	EDC Ranikhet						
19	Ranikhet	49.999	37156	3882.61	1206	12.384	213
20	Almora	48.671	31949	2691.74	748	6.548	246
21	Bageswar	25.88	20584	3301.96	850	8.647	129
22	Pithoragarh	56.881	43623	3926	1622	14.124	191
23	Champawat	28.199	18888	2523.59	702	5.480	123

Table A.2: Data for the Year 2006-07

S. No.	EDDS/circle	Energy Sold	Number of Customers	Distribution Line Length	Transformer Capacity	O&M Cost	Number of Employees
	EDC (R) Dehradun						
1	Dehradun (R)	192.685	52964	5513.61	943	15.612	158
2	Vikasnagar	21.002	26371	2296.81	661	4.473	101
3	Rishikesh	151.015	40621	1441.76	566	8.351	99
4	Uttarkashi	40.865	33067	2979.1	1512	11.721	188
	EDC (U) Dehradun						
5	Dehradun (N)	172.847	33380	1228.41	319	11.612	173
6	Dehradun (S)	204.264	47246	2176.33	349	13.689	165
7	Dehradun (C)	113.817	49576	447.55	314	7.753	149
	EDC Srinagar						
8	Srinagar	66.493	55745	3351.71	1496	6.542	273
9	Tehri	143.091	49768	5108.83	1699	15.13	244
10	Gopeswar	47.752	50372	3489.54	1346	15.875	227
11	Kotdwar	244.112	54187	4095.3	1458	14.038	221
12	Rudraprayag	19.02	30812	2868.54	1039	0.895	150
	EDC Roorkee						
13	Roorkee (U)	269.53	50342	3693.32	1381	8.177	139
14	Roorkee (R)	114.162	35991	10.35	2783	10.168	115
15	Haridwar (U)	448.81	48747	1640.33	578	9.86	153
16	Haridwar (R)	24.102	27647	1301.32	1380	3.16	107
	EDC Haldwani						
17	Nainital	61.036	34706	3300.82	858	2.162	180
18	Ramnagar	47.96	25258	1126.92	572	1.908	107
19	Haldwani (U)	81.111	32581	340.46	283	5.809	126
20	Haldwani (R)	123.612	31233	916.22	619	7.309	110
	EDC Rudrapur						
21	Kashipur	471.638	45952	1897.6	1444	13.182	222
22	Bazpur	160.704	15120	1003.45	725	2.534	71
23	Rudrapur	253.574	50597	2215.56	1574	9.286	151
24	Sitarganj	161.515	40924	2059.35	1196	5.231	90

	EDC Ranikhet						
25	Ranikhet	50.203	44403	3914.79	1242	14.073	212
26	Almora	44.787	36239	2762.32	782	6.534	230
27	Bageswar	25.136	27042	3321.68	853	6.753	129
28	Pithoragarh	59.539	50890	4011.33	1680	15.08	187
29	Champawat	29.937	24780	2510.07	709	5.715	116

Table A.3: Data for the Year 2007-08

S. No.	EDDS/circle	Energy Sold	Number of Customers	Duration of Interruption	Distribution Line Length	Transformer Capacity	O&M Cost	Number of Employees
	EDC (R) Dehradun							
1	Dehradun (R)	193.97	56858	15.24	7114.59	943	16.002	144
2	Vikasnagar	44.71	26858	15.80	2366.14	778	6.043	91
3	Rishikesh	167.46	44742	13.16	1384.93	566	7.735	126
4	Uttarkashi	42.15	33256	18.87	2852.25	1512	10.772	174
	EDC (U) Dehradun							
5	Dehradun (N)	148.24	34884	11.32	1278.54	348	11.057	155
6	Dehradun (S)	185.75	49943	3.35	2222.3	378	16.208	145
7	Dehradun (C)	182.52	51147	8.03	473.19	322	15.547	137
	EDC Srinagar							
8	Srinagar	68.62	59796	13.30	3922.41	1504	9.362	254
9	Tehri	159.54	53719	15.29	7354.99	1742	21.987	228
10	Gopeswar	45.76	54091	17.94	4772	1686	14.599	219
11	Kotdwar	256.38	59548	7.37	4598.6	2024	13.503	197
12	Rudraprayag	19.66	35102	23.07	3476.06	1106	11.742	131
	EDC Roorkee							
13	Roorkee (U)	200.51	55756	24.22	1343.45	1434	7.655	136
14	Roorkee (R)	278.29	39162	31.50	2445.08	3242	11.777	106
15	Haridwar (U)	428.02	50479	6.91	1620.09	669	8.372	153
16	Haridwar (R)	26.68	28631	21.97	1444.75	1533	3.28	57
	EDC Haldwani							
17	Nainital	70.53	37771	6.47	3338.07	885	9.747	173
18	Ramnagar	56.83	26650	3.72	1134.7	593	9.585	100
19	Haldwani (U)	90.03	33533	10.07	359.26	300	10.213	124
20	Haldwani (R)	155.58	34668	6.92	957.87	684	10.845	111
	EDC Rudrapur							
21	Kashipur	674.39	48546	35.00	4952.96	1568	15.745	209
22	Bazpur	215.09	16337	8.00	1014.88	736	3.362	67
23	Rudrapur	395.08	52943	9.52	2265.94	1696	8.86	146
24	Sitarganj	208.49	44433	9.38	2105.3	1239	10.493	86

	EDC Ranikhet							
25	Ranikhet	49.96	50041	9.57	4039.08	1266	12.071	210
26	Almora	47.38	37690	11.19	2811.43	806	7.122	234
27	Bageswar	30.05	32926	5.28	2924.78	1250	12.911	114
28	Pithoragarh	59.87	55851	11.6	4802.78	2230	20.882	173
29	Champawat	31.07	25070	7.78	3669.62	1085	9.806	109

Table A.4: Data for the Year 2008-09

S. No.	EDDS/circle	Energy Sold	Number of Customers	Distribution Line Length	Transformer Capacity	O&M Cost	Number of Employees
	EDC (R) Dehradun						
1	Dehradun (R)	214.969	64863	7114.59	944	12.641	125
2	Vikasnagar	41.883	29613	2395.62	788	9.333	94
3	Rishikesh	177.332	48195	1720.93	668	9.095	127
4	Uttarkashi	57.49	35510	2962.9	1633	13.61	169
	EDC (U) Dehradun						
5	Dehradun (N)	147.95	35986	1291.75	363	11.806	135
6	Dehradun (S)	197.655	52960	2230.94	385	9.916	144
7	Dehradun (C)	176.719	52712	486.8	337	15.658	142
	EDC Srinagar						
8	Srinagar	44.996	25547	4185.05	769	4.358	138
9	Pauri	27.953	38931	1597.93	956	3.678	112
10	Tehri	158.662	59251	8277.34	2368	21.847	212
11	Gopeswar	46.985	56068	4788.56	1702	13.975	198
12	Kotdwar	262.16	65033	4664.17	2084	11.374	193
13	Rudraprayag	22.989	41736	3477.02	1119	7.091	116
	EDC Roorkee						
14	Roorkee (U)	208.037	61458	1391.45	1756	9.064	116
15	Roorkee (R)	424.992	44483	2518.18	3520	19.222	92
16	Haridwar (U)	305.209	52804	1633.61	693	5.297	145
17	Haridwar (R)	554.759	34381	1637.13	1750	11.471	67
	EDC Haldwani						
18	Nainital	66.681	41894	1894.25	1101	10.126	174
19	Ramnagar	60.597	28456	1251.3	662	9.629	95
20	Haldwani (U)	94.017	35169	370.7	322	14.619	125
21	Haldwani (R)	169.511	37609	975.67	733	8.616	118
	EDC Rudrapur						
22	Kashipur	749.12	50861	2038.31	1711	18.993	209
23	Bazpur	211.218	16951	1018.84	757	3.633	71
24	Rudrapur	591.334	55666	2292.19	1930	12.552	141
25	Sitarganj	251.73	48748	2120.43	1245	5.715	88

	EDC Ranikhet						
26	Ranikhet	56.503	54500	4055.08	1287	10.195	190
27	Almora	52.967	39263	2870.01	830	13.089	221
28	Bageswar	32.833	36685	2978.95	1296	18.585	126
29	Pithoragarh	63.912	68425	5581.86	2668	44.473	164
30	Champawat	32.571	27313	3692.88	1155	18.922	115