CHAPTER 5
RESEARCH DESIGN

Chapter Objective:

- Roadmap for conducting the research.
- Listing the data collection methods used.
- Instrument used for analyzing data.

5.1 Research Design

To glean insights about Thermal power plants performance, it was initially decided to utilize as secondary as well as primary data. For secondary data, a request letter was sent by post to selected thermal power plants whose data was not available in public domain. It was also decided that other modes of collecting secondary data would be used, if the need arose.

5.2 Methodology

Data Envelopment Analysis (DEA) has been proven an effective tool in identifying the empirical frontiers and in evaluating the relative efficiency. DEA uses the mathematical programming to implicitly estimate the tradeoffs inherent in the empirical efficient frontier [74].

DEA is a decision making tool based on linear programming for measuring the relative efficiencies of a set of comparable units. The DEA Model was initially developed by Charnes, Cooper, Rhodes (1978). DEA is an empirically based methodology that eliminates the need for some of the assumptions and limitations of traditional efficiency measurement approaches. The basic DEA model as introduced by Farrell [30] and later developed by Charnes, Cooper and Rhodes (CCR Model) uses an oriented radial measure of efficiency, which identifies a point on the boundary with the same mix of inputs (input orientation) or outputs (output orientation) of the observed unit. As a result, DMUs can be assessed on the
basis of multiple inputs and outputs, even if the production function is unknown. It is a non-parametric approach to solve a linear programming formulation for each DMU and the weights assigned to each linear aggregation are the results of the corresponding linear programming (Charnes et al) [13].

Assuming nothing on DEA variables, weight is in one important strength of this method because if DEA assume or attach weights to criteria (like in MCDM), it take the risk of modeling the preference structure inside the decision maker's mind, and even if DEA do it well (which is not easy), one do not really know if there are not other valid models (with different criteria or different criteria weights) that could have been used instead of that one, and which would produce different results. There is certain subjectivity in this.

If one have historical data on several alternatives (particularly if they are DMU's - decision making units) then DEA is very interesting because instead of building on subjective criteria weights, it takes real life performance of other decision making units as a reference to compare each DMU with. So one don't subjectively decide what matters most in the comparison, just consider that if certain DMU's manage a certain real combination of inputs and outputs, than it could have done equally well as a linear combination of their "decisions" and if it don't, one can improve. So, in a way, it builds on reality and not on assumptions.

DEA criteria weights vary freely, which faces one disadvantage of this: any DMU that performed best in one criteria even if it is worst in all others, will be considered efficient because it will maximize the weight on that criteria. But this pitfall can be overcome with carefulness, not to have more criteria that alternatives (preferably have a lot more alternatives than criteria) to minimize the chance that this happens. If one does so, it is just a small pitfall.

About DEA being old approach, since it is still very popular, it is only a sign that it passed over the times test. If it were bad it would have been discontinued already. One just has to be careful how to use it and derived the results in very concluding way.
As a final remark, DEA should be for learning and improvement and not for reward or punishment, so one should not evaluate DMU's for criteria over which they have no control. This is something people often neglect.

5.3 Scope of the Study

The scope of the study covered ten financial years viz., 2002-03 to 2011-12 to measure the operational efficiency of coal/lignite fired thermal power plants located all over the India with special preference to Gujarat State. 74 coal/lignite fired power plants are included as sample to measure the average productivity change of Indian coal-fired power plants during the 2002–03 to 2011-12. The results of the study should be viewed in the background of limitations such as sample size, sampling technique, prevalent laws and the duration of the study. This study focuses on the production side of power generation industries. In this sector also, the choice on the input side is generally driven as much by data availability as it is by economic principles. Maximum of variable selected are based on data availability factor. Secondary data had used extensively for research work. Over and above the secondary data, expert’s opinion had taken on selecting the variables as input or outputs. Publicly disclosed information e.g., information reported with Central Electricity Authority (CEA) by this power plants company is considered as correct, regardless of whether the company actually achieved or not.

As these being generally reputed companies, it was thought that the findings and recommendations of this study may serve to project exemplary practices for other companies to emulate.

5.4 Sources of Data

The sources of data and information for the study are the websites of selected companies, as well as annual reports. As majority of the thermal power plants operating in India has to compile the statutory requirement of CEA and other statutory bodies of the
State/Central, it has been widely used as secondary data for our research study. As major focus is on Gujarat’s thermal power plants operating under State government, Central government or Private owned, our research is restricted to specific coal based thermal power plants. For comparison purpose few PSUs have been selected from other regions like Maharashtra, Orissa, etc.

5.4.1 Data Description & Measurement of Input and Output Variables

Definitions

Following are the details of the definition for different important variables used in the study under different models [51, 64, 65].

Capacity (MW)

Capacity means the installed or derated/uprated capacity of unit as accepted by CEA. Generally, a power plant will describe their capacity in terms of 'Megawatt hours’ (MW/hr). This means how many megawatts can be produced per hour. For example: thermal power plant can produce 125 MW/hr. It will be termed as 125 MW power plant or unit. In our research study capacity is included as input variable.

Generation (MU)

In normal phenomenon, energy generated by power plants or units are measured in Million Units (MU). For example 125 MW power plant or unit can produce 125 MW/hr. If that plant is running at full capacity all day then it will produce a total of 3000 MW or 3 MUs each day and 1095 MUs yearly. As generation of energy is the final product of the power plant, it is included as output variable.

Planned Maintenance (PM)

Maintenance which is performed purposely and regularly in order to prevent a machine from deteriorating or breaking down is known as planned maintenance (as shown in
During the research, planned maintenance has been measured in terms of energy loss of % of maximum possible generation.

Planned outages are due to overhaul (or other) work which is planned well in advance. It is considered as input variable.

\[
Planned\ Maintenance\ (in\ \%) = \frac{\text{energy lost due to planned outages (MWh)} \times 100}{\text{Total installed capacity (MW) \times period hours}}
\]  

Equation 1)

**Forced Outage (FO)**

The removal from service availability of a generating unit, transmission line, or other facility for emergency reasons., The condition in which the equipment is unavailable due to unanticipated failure. It is known as forced outage. In other words, forced outages require the removal of a generating unit from service for repairs that have not been planned. It is considered as input variable.

\[
\text{Forced outage\ (\%) = } \frac{\text{Energy lost due to forced outages (MWh)} \times 100}{\text{Total installed capacity (MW) \times period hours}}
\]

Equation 2)

**Operating Availability (OA) or Operating Availability Factor (OAF)**

The availability factor of a power plant is the amount of time that it is able to produce electricity over a certain period, divided by the amount of the time in the period. Occasions where only partial capacity is available may or may not be deducted. In other words, availability is an indicator of the maximum amount of electrical energy that a unit is able to generate during a period, after making allowances for outages due to all causes. It is included as output variable.

\[
\text{Operating\ Availability\ Factor\ (OAF)\ (\%) = } \frac{\text{total installed capacity (MW) \times period hours} - \text{MWh losses due to all outages during the period} \times 100}{\text{total installed capacity (MW) \times period hours}}
\]

Or

\[
\text{Operating\ Availability\ Factor\ (OAF)\ (\%) = 100 – FO – PM}
\]

Equation 3)

**Reserve Shutdown + Low System Demand (%)**
Low Load (%) comprises of low system demand and reserve shutdown. When operating units generate less due to system load variation then it is termed as low system demand. Non-utilisation of available units due to their complete shutdown for want of load is known as reserve shutdown.

**Partial unavailability (Partial loss) (%)**

When there is reduction in the output of the operating units in MW due to constraints in auxiliaries/equipments or any other causes and units are operating at reduced load. Such situation is termed as partial unavailability.

**Plant Load Factor (%)**

The ratio of the total number of kWh supplied by a generator or generating station to the total number of kWh which would have been supplied if the generator or generating station had been operated continuously at its maximum continuous rating.

\[
\text{Plant load factor(%) = } \frac{\text{Energy generated (MkWh)} \times 10^5}{\text{Installed capacity (MW)} \times 8760}
\]  

(4)

**Auxiliary Consumption**

All electricity consumed internally within the boundary of a power station or cogeneration plant to run the plant is termed as auxiliary consumption. It plays an important role assessing the performance of any power plant. It is considered as input variable for study purpose.

\[
\text{Auxiliary consumption(%) = } \frac{\text{Auxiliary consumption (MkWh)} \times 100}{\text{Total generation (MkWh)}}
\]  

(5)

**Special Oil Consumption**

Special oil consumption is measured in Ml/kWh and considered it as input variable.

**Special Lignite Consumption**

Special lignite consumption is important raw material for generation of electricity and it is measured in Kg/kWh and considered as input variable.
Total Outage Duration (Hrs)

Total outage duration means equipment is unavailable either due to unanticipated failure or due to preventive measure which are performed purposely and regularly to avoid deterioration or breaking down. Total outage duration is simply calculated with addition of planned maintenance and forced outages.

\[ Total\ Outage\ Duration(hrs) = PM + FO \]  

Operating Hours

Here operating hours means that total number of hours during which a unit generates electricity over a period of time.

Total Capital Employed

Total capital employed includes net worth, total loans, consumers’ contribution and grants. It is included in study as input variable. The formula represented as under:-

\[ Capital\ Employes = net\ worth + total\ loans + consumers\ contribution + grants \]

Power Purchased

Here power purchase (MkWh) is included as input variable for utilities selling directly to consumers. In normal course of action these utilities are buying power from various generating stations or units through purchasing power agreement (PPA) and transmitted to end consumers.

Generation Cost

All the cost related to generation is categorized as generation cost. It broadly includes consumption of stores, spares & chemicals, electric power, electricity duty and water, contract job outsourcing expenses, insurance, other generation expenses, repairs to buildings, repairs to machinery etc. It is included as input variable.

Employees Cost
Here employees cost refers to expense related to employee benefit. It broadly includes salaries & wages, contribution to provident fund & gratuity and other staff welfare expenses. It is included as input variable.

**Operation & Maintenance Cost (O & M)**

All the cost related to operation and maintenance of power plant is considered as input variable.

**Energy Sold (MkWh)**

Electrical energy leaving the power plant is termed as Energy sold. This is the generated energy minus the auxiliary energy used in the plant.

\[ \text{Energy Sold (MKwh)} = \text{Energy generated (MWh)} - \text{Auxiliary energy (MWh)} \quad (8) \]

**Sale of Power (Rs Crores)**

Here sale of power means the aggregate revenue from sale of power for SEBs, State power departments and DISCOMs selling power directly to consumers.

**Collection Efficiency (%)**

Collection efficiency ratio is one parameter used by energy planner in power distribution industry to evaluate amount realized to amount billed. As a performance indicator, it compares actual collections with what is supposed to be collected by power distributor’s house.

\[ \text{Collection Efficiency} = \left( \frac{\text{Net Revenue from Sale of Energy} - \text{Change in Debtors for sale of power}}{\text{Net revenue from sale of energy}} \right) \times 100 \quad (9) \]

Or

\[ \text{Collection Efficiency} = \frac{\text{amount realised}}{\text{amount billed}} \times 100 \]
Aggregate Technical and Commercial Losses (%)

It is the difference between energy input units into the system and the units for which the payment is collected. AT&C Loss is the actual measure of overall efficiency of the distribution business as it measures both technical as well as commercial losses.

\[
ATC \text{ Loss} \% = \frac{(\text{energy input} - \text{energy realised}) \times 100}{\text{energy input}} \quad (10)
\]

\[\text{Energy Realised} = \text{energy billed} \times \text{collection efficiency}\]

Total Income

Total income includes revenue from sale of power and income from other sources but excluding subsidy.

\[\text{total income} = \text{revenue from sale of power} + \text{other income excluding subsidy} \quad (11)\]

Total Expenditure

Total expenditure includes all the expenses which have been incurred during the process of doing business.

Average Cost of Supply (Rs/kWh)

Avg. Cost of supply is calculated as under:

\[\text{Avg. cost of supply} \left( \frac{\text{Rs}}{\text{kWh}} \right) = \frac{\text{Total Expenditure}}{\text{Total input energy (kWh)}} \quad (12)\]

Average Revenue (Rs/kWh)

Average Revenue is calculated as under:

\[\text{Average Revenue} \left( \frac{\text{Rs}}{\text{kWh}} \right) = \frac{[\text{revenue from sale of power(excluding subsidy)+ other income}]}{\text{total input energy (kWh)}} \quad (13)\]

\[\text{Gap} \left( \frac{\text{Rs}}{\text{kWh}} \right) = \text{ACS} - \text{Average Revenue} \left( \frac{\text{Rs}}{\text{kWh}} \right) \quad (14)\]

5.4.2 Selection of Inputs and Outputs & Purification of Data

There is on-going discussion in the power sector literature regarding the proper definition of inputs and outputs. In detail it has been discussed in literature review. Till today, there is no agreement on the explicit definition and measurement of power sector inputs and
outputs. Different approaches appear in the literature regarding the measurement of inputs and outputs of a power sector. Try to highlight in tabular form the inputs and output used in research study over a period of time.

**Table 5.1: Defining of Variables as Input and Output**

<table>
<thead>
<tr>
<th>Input Variable</th>
<th>Output Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (MW)</td>
<td>Generation (MU)</td>
</tr>
<tr>
<td>Planned Maintenance (%)</td>
<td>Operating Availability Factor (OAF)</td>
</tr>
<tr>
<td>Forced Outage (%)</td>
<td>Plant Load Factor (%)</td>
</tr>
<tr>
<td>Reserve Shutdown + Low System Demand (%)</td>
<td>Operating Hours (Hours)</td>
</tr>
<tr>
<td>Partial Unavailability (%)</td>
<td>Energy Sold (MkWh)</td>
</tr>
<tr>
<td>Auxiliary Consumption (%)</td>
<td>Sale of Power (Rs Cr)</td>
</tr>
<tr>
<td>Special Oil Consumption (MI/kWh)</td>
<td>Collection Efficiency (%)</td>
</tr>
<tr>
<td>Special Lignite Consumption (Kg/kWh)</td>
<td>Total Income (Rs Cr)</td>
</tr>
<tr>
<td>Total Outage Duration (%)</td>
<td>Average Revenue (Rs/kWh)</td>
</tr>
<tr>
<td>Total Capital Employed (Rs Cr)</td>
<td></td>
</tr>
<tr>
<td>Power Purchased (Rs Cr)</td>
<td></td>
</tr>
<tr>
<td>Generation Cost (Rs Cr)</td>
<td></td>
</tr>
<tr>
<td>Employee Cost (Rs Cr)</td>
<td></td>
</tr>
<tr>
<td>Operation and Maintenance Cost (Rs Cr)</td>
<td></td>
</tr>
<tr>
<td>Aggregate Technical and Commercial Losses (%)</td>
<td></td>
</tr>
</tbody>
</table>
5.5 Sampling Plan

This research work studies the effect of various input and output variables on India’s thermal (coal/lignite) power generation unit with special preference to Gujarat power industry. During the research, DEA model has been used to highlight best DMU lying on efficient frontier in industry. Further, this study researches the event that had already taken place and no control is exercisable over the variables. Hence, this study is ex-post facto causal-explanatory in nature. As far as sample size is concern; all the thermal power generation units are included, using Coal & Lignite, Natural Gas & Liquid fuel for generating electricity in the Gujarat region as well as in India except captive plants. Thus, purposive (deliberate or judgment) sampling technique is used for deciding the sample for the study. All the samples are referred as DMUs in Data Envelopment Analysis as shown in Table 5.2.

Table 5.2: List of Coal/Lignite Fired Power Plants Operating in Gujarat Region

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Particular</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Surat Lignite Power Plant – (SLPP)</td>
<td>GIPCL</td>
</tr>
<tr>
<td>2</td>
<td>Akrimota Thermal Power Station</td>
<td>GMDC</td>
</tr>
<tr>
<td>3</td>
<td>Wanakbori Thermal Power Station</td>
<td>GSECL</td>
</tr>
<tr>
<td>4</td>
<td>Sikka Thermal Power Station</td>
<td>GSECL</td>
</tr>
<tr>
<td>5</td>
<td>Kutch Lignite Thermal Power Station</td>
<td>GSECL</td>
</tr>
<tr>
<td>6</td>
<td>Sabarmati Thermal Power Station</td>
<td>Torrent Power</td>
</tr>
</tbody>
</table>
Table 5.3: List of Gas/Liquid Fuel Fired Power Plants Operating in Gujarat Region

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Particular</th>
<th>Operator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dhuvaran Gas CCPP I &amp; II</td>
<td>GSECL</td>
</tr>
<tr>
<td>2</td>
<td>Utran CCPP</td>
<td>GSECL</td>
</tr>
<tr>
<td>3</td>
<td>GIPCL CCPP-I</td>
<td>GIPCL</td>
</tr>
<tr>
<td>4</td>
<td>GIPCL CCPP-II</td>
<td>GIPCL</td>
</tr>
<tr>
<td>5</td>
<td>Torrent Power Gas</td>
<td>Torrent Power</td>
</tr>
<tr>
<td>6</td>
<td>Essar Power</td>
<td>Essar</td>
</tr>
<tr>
<td>7</td>
<td>GSEG CCPP</td>
<td>GSEG</td>
</tr>
<tr>
<td>8</td>
<td>GPEC CCPP</td>
<td>GPEC</td>
</tr>
<tr>
<td>9</td>
<td>Sugen</td>
<td>Torrent Power</td>
</tr>
</tbody>
</table>

Diesel based power plants have been stopped long back in Gujarat region. Major focus is on coal/lignite based power plants to meet current demand for various sectors. Subsequently in recent years Gujarat government has shown special interest in developing the renewable sources of energy i.e. solar and wind.
The objective of this study is to capture the importance of input variable on the overall performance of the DMUs. Here the study is limited to the selected DMUs operating in India /Gujarat region and measuring technical efficiency of Gujarat’s thermal power generation industry considering valuable input & output variables and then comparing with all India performance.

5.6 Data Collection

The response to the endeavor to generate primary data was inadequate. Therefore, the work proceeded on the basis of secondary data. Secondary data was collected as following:-

1. The main sources of data collection are official websites, annual reports, books, journals and articles, newspapers, magazines, case studies.

2. Basic data on India’s power generation industry has been extracted from Central Electricity Authority, Ministry of Power & from other official websites of Government.

3. Data related to Gujarat’s thermal power generation Industry has been compiled from different secondary as well as primary sources.

4. An industry people and industry expert has been interviewed in order to validate the data collected from the above sites and databases.

Secondary data and information used from various sources for the study was for the decade i.e. ten financial years viz., 2002-03 to 2011-12.

5.7 Data Processing and Analysis

After collecting data through various data collection methods listed above, data is analyzed using the software called Data Envelopment Analysis Program (DEAP) Version 2.1 [14]. This is done to know the efficiency and performance of the selected DMUs and appropriate statistical techniques to test relevant hypotheses in order to achieve the objectives.
of the study. It also highlights the slacks in various selected inputs and output variable and
direction to improve their performance and become efficient.

5.8 **Formulated Hypothesis**

During the research period three hypotheses are included and tested. As groups are
independent, t-test for independent groups is applied on all formulated hypothesis.

a) **Hypothesis**

\[ H_0 : \text{the mean of the Technical Efficiency of the old power plants is the same as the mean} \]
\[ \text{of the new power plants Technical Efficiency (Null Hypothesis).} \]

\[ H_1 : \text{the mean of the Technical Efficiency of the old power plants differs from the mean of} \]
\[ \text{the new power plants Technical Efficiency (Alternative Hypothesis).} \]

b) **Hypothesis**

\[ H_0 : \text{the mean of the Technical Efficiency of the Pithead power plants is the same as the} \]
\[ \text{mean of the simple power plants Technical Efficiency (Null Hypothesis).} \]

\[ H_1 : \text{the mean of the Technical Efficiency of the Pithead power plants differs from the} \]
\[ \text{mean of simple power plants Technical Efficiency (Alternative Hypothesis).} \]

c) **Hypothesis**

\[ H_0 : \text{there is no linear dependence between PTE and PAT (Null Hypothesis)} \]

\[ H_1 : \text{there is a linear dependence between PTE and PAT (Alternative Hypothesis)} \]

5.9 **Limitations**

The study is focused on the coal/lignite fire power generation industry of India with
special reference to Gujarat State. Hence, the results of this study may not be generalized to
other industries as well as within the industries with different power generation options. The
results of the study should be viewed in the background of limitations such as sample size,
sampling technique, prevalent laws and the duration of the study. Publicly disclosed
information e.g., in the annual reports is considered as correct, regardless of whether the company followed it or not in actual practice.

At many stages, the basic objectives of the study suffered from inadequacy of time-series data for Gujarat power generation units and change of ownership part.