Joint Efficiency Analysis of Thermoelectric Power Plants in Pakistan

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Certificate

This thesis by **<u>Imran Ali</u>** is hereby accepted in its present form by the

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Abstract

The study undertakes efficiency analysis of thermal power generation in Pakistan with an eco-efficient perspective. Eco-efficient behavior ensures sustainability of nature, while eliciting the economic growth. Thermal power generation has a lion's share in the fuel mix of the energy sector in Pakistan. The economic and environmental efficiency of 32 thermoelectric power plants was determined by Stochastic Frontier Analysis. The efficiency analysis revealed that none, among 32 thermoelectric power plants were operating on the efficiency frontier. The efficiency scores in two scenarios ranged between 0.50 - 0.65. The analysis showed that coal is the most inefficient technology, followed by Furnace Oil. However power generation by Gas is comparatively cheaper and environmentally less detrimental. Plants with higher generation capacities, and plant operated by private entrepreneurship turned out to be more efficient than the small plants, and state owned plants. Coal has the highest shadow cost Rs.8.54followed by Furnace Gil and Gas. The study concludes that power generation by combustion of fossil fuel is highly inefficient, both economically and environmentally. Therefore it is acclaimed that energy policies must be intertwined within the eco-efficient criterion. Moreover the study suggests the restoration of hydropower generation, which is both economically and environmentally valiant.

Dedication

To the Lady of Universe and Paradise, The Healer and Exalted,
Hazart Fatima Zehra (SA),
and the one who always stood beside me,
in my successes and in my failures, in my sorrows and in my felicities,
to my beloved father
Al-Haj Muhammad Ismail

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Imran Ali

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Acronyms

BTU	British Thermal Unit
Cal	Calorie
Cft	Cubic Feet
CNG	Compressed Natural Gas
CRS	Constant Returns to Scale
DISCO	Distribution Company
DMU	Decision Making Unit
ESCO	Electricity Supply Company
FBC	Fluidized Bed Combustion
F.Oil	Furnace Oil
ft^2	Cubic foot
GENCO	Generation Company
GTPS	Gas Turbine Power Station
gWh	giga Watt Hour
IPCC	Intergovernmental Panel on Climate Change
HSD	High Speed Diesel
HUBCO	The Hub Power Company
KANUPP	Karachi Nuclear Power Plant
KAPCO	Kot Addu Power Company
KESC	Karachi Power Company
kWh	Kilowatt Hour
LP	Linear Programming
LPG	Liquefied Petroleum Gas
ML	Maximum Likelihood
MW	Mega Watt
SBM	Slacks-Based Measure
SFA	Stochastic Frontier Analysis
TPS	Thermal Power Station
TOE	Tones Oil Equivalent

Chapter.1 Introduction

The current era has happened to be an energy extensive age. Today we require energy not only for transportation and for manufacturing; rather our lives are dependent on energy. Over the course of time, human race has been employing waterpower, animals, wood, coal, oil, gas, wind nuclear and solar energy to meet its demand of energy. Energy has played a significant role in economic growth globally, and maintained to be a vital input to the global economic activites. Human development depends upon provision of affordable, safe and sufficeint energy supply. With the industrial revolution, the increase in demand for energy accelerated the extraction of fossil fuels, especially extraction of coal that fueled the Industrial revolution and fossil fuels were thought to be the ideal energy sources. See [Eric and Darlod (2011)].

Global energy mix today is highly dependent upon fossil fuels, according to Global Energy Outlook by National Geographic Special 80 percent of global energy demand supplies comprise of fossil fuels. The exploration, extraction and employment of fossil fuels; to meet the demand of energy is accompanied by unrestrained emissions of combustion offshoots, that includes emission of CO_2. The bionetwork and sustainability of atmosphere is facing undesirable and adverse implication from the consumption of enormous amount of energy that results in environmental degradation, which threatens the ecological balance, biological diversity, human health and the quality of life. It is therefore essential to meet up the global energy demands neither harming the bionetworks and degrading the life quality, nor hampering the economic growth.

Electric energy is unique, as it is easier to transport over long distances inexpensively and is converted into any other form at point of consumption. Electric energy is not available directly; it is generated by transforming energy of other types, for instance the chemical energy into thermal, the thermal in to mechanical, and mechanical energy is then transformed into electric energy. Electric energy could not be stored for long duration, in order to use it in future. Consumer demand fluctuates with the time of the day, and seasons, therefore the main electricity producers are thermal electric power plants. They use fossil fuels that could be stored and the combustion of fossil fuels invigorates the crisis of global climate change. [Agency (2011)]. Today the thermal power plants are the main source of electricity generation across the world; generate about 66.6percent of the world electricity, and is a threat to global climate change and sustainability of bionetworks and economic resources.

Sustainability refers to balance the societal demands on the environment and societal well-beings, both for the current and upcoming generations. The objective of sustainability is to lessen the environmental and social negative externalities and to maximize human well-being. [Chambers,*et al* 2000)] are of the view that" to make sustainability happen, we need to balance the basic conflict between the two competing goals of ensuring a quality of life and living within the limits of nature".

There are two key and contradictory notions of sustainability. The first one believes that the only sustainable way of consumption is consume less. They are critical of the relationship between consumption and well-being. It suggests that because consumption levels and well-being are not correlated so, the reduction in consumption would not affect the level of well-being. In contrast, other view is based on the perception that reduction in consumption is absurd and it gets in the way of utility. Andrew and Brett (2011) and, Arthur and David (2004) are of opinion that if sustainability needs to reduce the level of consumption, then the current nation will face a miserable tradeoff between their own level of well-being and that of the forthcoming generations. The idea relied upon the assumption of neoclassical economics; that well-being or utility is equal to the level of consumption. The way out of the problem suggested is to make the consumption benign, or in more efficient way. The sustainability therefore rests upon the efficiency. Man can ensure sustainability in every sphere by adopting the course of efficiency, and it's the only benevolent way of consumption, for both the current and forthcoming generations.

Efficiency is a phenomenon related to both environmental and economic performance. Achieving environmental efficiency may unavoidably increase the cost and my cut down the productivity. Environmental degradation is a negative output and chops down the utility, and requires additional input to decrease the environmental degradation; therefore, any environmental improvement that cannot enhance economic efficiency is a win-loss model. However, a group of researchers considers environmental improvements and cost, are of view that pollution is both environmental and economic externality and results in economic inefficiency.

Another school rants the traditional model of pollution control and the abatement cost. They are of view that the cost incurred in environmental improvement is a win-win situation. Public policies must ensure the adoption of innovative and creative methods to produce the same level of goods and services while reducing the environmental damages and resource. These policies are termed as eco-efficient behavior; the only rational behavior of an entrepreneur is eco-efficient behavior. See [King and Lenox (2002)].

Pakistan, since 2005 is going through the nastiest energy crisis. Frequent outages and mounting prices of other forms of energy have turned Pakistan into an energy busted economy. The urban areas are experiencing regular load shedding of eighteen to twenty hours a day due to 5000-7000MW deficit in supply. The importunate energy crisis has adverse impacts on economy, and is a constant threat to social harmony. The failure of power sector has deteriorated the manufacturing sector. The total industrial output losses due to power failure are about 12 to 37 percent.[Siddiqui, *et al* (2011)]. Literature implies several reasons behind such an enormous demand supply gap at macro-level. Failure of Public Policies to entwine the generation capacity with the increasing demand , rapid growth in demand, the circular debt issue , inadequate fuel mix of generation and high system losses due to obsolete technology are among numerous reasons behind the energy crisis.

As the generation is highly dependent on oil fired power plant therefore generation costs has increased many folds since the oil prices in international market have escalated. Due to shortage of natural gas supply to the generation plants many oil fired plants have been transformed into gas fired plant, moreover the new plants added to national generation capacity are furnace oil fuel operation systems. The price of furnace increased from Rs18,000/ton in 2005 to Rs 63,000/ton in 2010. Likewise the hydro sector is facing a declining trend and since the construction of Ghazi Barotha Dam in the year 2004, no new hydro project has been added to enhance the share of hydro sector in national generation capacity.

Publicly owned GENCOs comprise 1/3rd of the total thermal power plants of the country and are significantly important in the national generation capacity. However due to improper maintenance and upkeep their generation capacity has depreciated with the passage of time. The depreciated generation capacities of few thermoelectric power plants in Public Sector are shown in Table.1 in Appendix.

To ensure efficient production increase in the cost of production must be adjusted in the prices. But in case of Pakistan though the generation cost of electricity has increased many folds, but government is unable to transfer the cost of generation to the end users. A huge gape lies between actual prices and the charged prices. The prices of electricity are determined for each DISCO, keeping in view the cost, losses and the consumer mix but government emphasizes on applying an even price per unit, across the country; that results in the financial losses to both GENCOs and DISCOs. These losses are then compensated by subsidies, and the subsidies are not paid due to peculiar financial conditions of the government. DISCOs transfer the losses to NTDC which ultimately falls on the power producer. IPPs are therefore reluctant to generate electricity, due to shortage of funds to pay the fuel suppliers. See details in Table.2 in Appendix.

The distribution losses are intensifying the energy crisis. No heed has been paid to upkeep the rotten and disintegrated distribution line. The higher distribution losses increase the per unit cost of electricity, and with the uniform price across the country the DISCOs are unable to adjust their prices on basis of line losses, augmenting the financial burdens of DISCOs. See Table.3 for details in appendix.

Despites adequate generating capacity the generation of electricity is in short supply. Thus the issue needs to be studied at micro level to sketch out the causes of energy crisis and to chalk out remedies of failure and to formulate policy guidelines for efficient and effervescent power sector; an energy sector that can ensure inexpensive, sufficient and safe provision of electricity. Though all these macro level factor of energy crisis are responsible for the crisis, however micro-level setbacks i.e at level of plant and consumer has been ignored. Policies must pay heed to the guarantee higher efficiency on micro level for both consumption and production of electricity in Pakistan. No studies have been carried out to examine the pattern of inefficiencies on the consumption side.

The study is an attempt to examine the crisis from a bottom-up approach. The efficiency will be analyzed at micro-level, from two different perspectives. Micro-level analysis will bring up causes of ineptness, inefficiency and uneconomic aspects of the plants. The study uses the eco-efficient approach, keeping in view the sustainability of the environment to provide guidelines for both the national energy policy and environmental law. Moreover as the study is using eco-efficient approach, that integrates both economic efficiency and environmental efficiency that will help the policymakers to determine the environmental costs of production and could be employed for environmental regulations. Moreover the study inspects the productivity of factors that may be handy to determine the fuel mix in future.

The objectives of study are:-

1. Examine the Economic Efficiency of thermal power plants in Pakistan
2. To study the Technical Efficiency of thermal power plant in Pakistan
3. To study the Environmental efficiency of thermal power plants in Pakistan

4. The study aims to estimate Shadow Prices of CO_2 for Thermal Power generation with a vision to use the shadow prices as policy instrument for environmental regulations, energy planning and provide guidelines for CO_2 trading.

The study aims to test the null hypothesis of existence of technical, economic and environmental efficiency in both public and private Thermal Power Plants in Pakistan.

The study will focus that how does the difference of fuel type impacts the production and eco-efficiency of the production. How much the ownership and entrepreneurial differences of the private and public power plants effect the efficiency of thermoelectric power plants in Pakistan. Moreover the study will examine how the age of the plant and generation capacity of plant impinges on the eco-efficient productivity of the plants. The study will figure out the shadow prices of the emission of fossil fuels, and will try to use it as economics and environmental tool in policy mechanisms.

Chapter.2 Literature Review

In economic literature efficiency of a firm is measured by focusing on its output per input. From this angle a firm would be efficient with maximum output per unit input. In the case of power generation entities, an efficient plant will generate maximum power per unit of factors of production. Efficiency is no more a relation between capital invested and output generated. Social and aesthetic values have been integrated into economic models, which gave a new meaning to the term efficiency in economic literature. Though a diversion from the basic production theory, which emphasize only on output per unit of input but scholars have begun to include environment, social values in their models of productivity. These scholars are of view that productivity in true sense increases, only after it has been gone through process of accounting for environmental performance. See [Tyteca (1997)], [Fare and Pasurka (2007)].

One can find many approaches that integrated environmental performance for productivity analysis. Some researcher calculated shadows prices for the pollution that is made during the process of generation or production. These shadow prices are then adjusted to measure the productivity of inputs. See [Aiken and Pasurka(2003)] Other approaches include Malmquist-Luenberger Index, which maximizes outputs while reducing bad outputs at once. See [Saleem (2005)], [Bevilacqua and Braglia (2002)].

In the estimation of a frontier production frontier in order to predict maximum possible output from inputs are stochastic frontier analysis and data envelopment analysis. Data envelopment analysis is the non-parametric approach that incorporates linear programming to sketch a frontier; it does not entail assumptions related to structure of the production function. It constructs the best practiced production function empirically by including observed input and output. Data envelopment analysis is not capable to differentiate technical inefficiency and random error. See [Admassie & Matambalya (2002)] and [Vu (2003)]. While stochastic frontier analysis is a parametric approach, and it is assumed that functional form of production function is known and could be estimated statistically. SFA has advantage to explore the other parameters of technology, hence allows to test a hypothesis with statistical rigor. It simultaneously estimates the technical efficiency and technical inefficiency effect models. See [Zahid and Mokhtar (2007)].

Efficiency analyses of power generation plants started in 1970 in the economic literature; however the major concern, the studies focused was the issue of ownership, less heed was paid to other determinants of inefficiency for example the type of fuel, plant age and scale of production. With the passage of time the studies however included other determinants of plant efficiency. Moreover external factors that may influence the efficiency like market share of industry, the laws and regulation of the economy were taken into consideration, in the economic studies.

Ownership of the plant is a major concern and it significantly impacts the efficiency of the generating plant. Numerous studies have been carried out to examine the impact of ownership on efficiency of the plants. The studies show that private plants are more efficient than the public ones, as their only aim is to maximize the profits rather than the provision of public service. See [Sarica and Or (2007)], [Berg, Lin and Tsaplin (2005)] and [Saleem (2005)]. However some studies show that the public owned plants are more efficient due to scale of production and regulation by government. Some studies concluded that ownership has no direct impact on the efficiency of a plant however the technical efficiency of a plant much depends upon the ownership of the plant. See [Khanna, Mundra and Ullah (1999)] and, [Sarica and Or (2007)].

Generating capacity is term for highest and uninterrupted level of output of a plant. It could be called the scale of production for the thermoelectric power plant and is one of most important determinant of efficiency studies. Several studies show direct linkages between efficiency and plant size and found that higher the level of output higher is the efficiency. See [Fallahi, Ebrahimi and Ghaderi (2011)] and [Thakur (2006)]. However [Sarica and Or (2007)] concluded that bigger sizes of plant have their negative impacts on the efficiency, and bigger plants frequently face managerial, maintenance and operational issues.

Technology is the most important determinant of efficiency and unfortunately there is no viable way to incorporate technological progress into productivity analysis. However efforts have been made to incorporate technological progress. The plant age is used as proxy for the technology. [Barros and Peypoc (2007)] concluded that plant age significantly impacts the efficiency level, newly build plants were found more efficient than the old ones. However a few studies found that older plants are more efficient due higher level of managerial skills and better experience. See [Pollitt (1996)] and [Eric and Darlod (2009)].

The generation capacity of a plant depends upon the thermal efficiency, which depends upon the type of fuel combusted therefore in power generation industry the fuel type is assumed as determinant of the efficiency. Gas fired plants exhibits greater efficiency than the coal fired plants. See [Fallahi, Ebrahimi and Ghaderi (2011)], and [Coelli and See (2011)]. However some studies found that the difference of fuel type had no impact on technical and economic efficiency. Fuels with Higher Heat contents and greater calorific value tend to be environmentally inefficient due to higher emission rates and low productivity for example coal having higher heat values and greater calorific value appears to be environmentally inefficient, but being economical it appears to be financially efficient.

Emissions are the bad outputs, and if the productivity analysis is going through environmental accounting, emissions reduce the productivity of factors. Therefore for eco-efficient analysis of productivity many efforts have been done to include environmental factors, emissions in case of power generation. The empirical results show that higher the generation; lower will be the emission level. Therefore the studies recommend to innovate and adopt ecological friendly technologies in thermal power generation, or to substitute thermal power with less emitting sources like hydro, solar nuclear and wind power generation. See [Eric and Darlod (2009)] and [Vaninsky(2008)].

Economic efficiency analysis of thermoelectric power plants includes Capital, Labour and generating cost as the determinants of the efficiency. However the studies concluded that capital and labour are the secondary determinants of the efficiency analysis and found no direct correlation between joint efficiency and capital. Studies that undertook only economic efficiency analysis concluded and ambiguous relationship between number of labours and economic efficiency. However fuel cost per unit of generation is much important for efficiency analysis. Efficiency much depends upon the cost of fuel per unit generation of electricity. See [Adnan, Ihsan and Adnan (2010)].

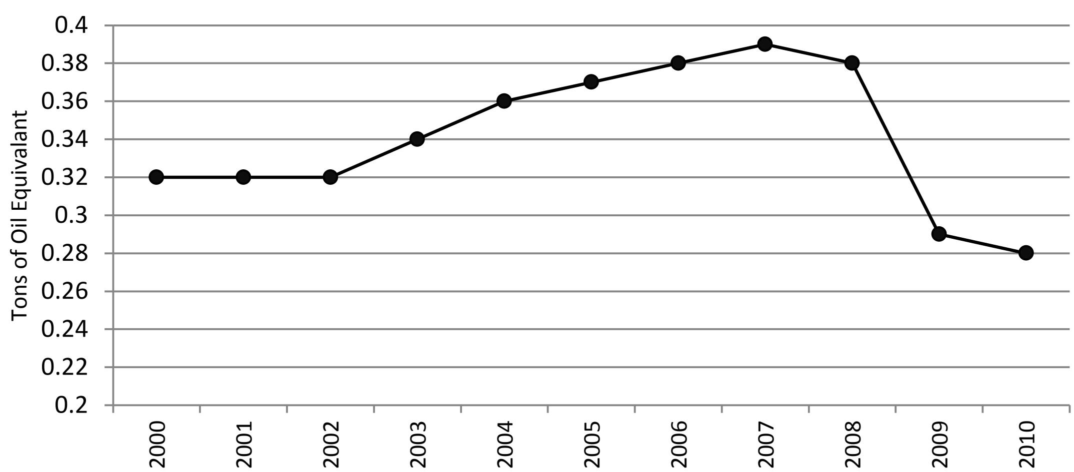
After the successful commencement of CO_2 Emission Markets, now it is possible to trade CO_2 Credits. Introduction of carbon markets has its own pros and cons. It has severely affected the environmental efficiency of thermal power plants. Pollution permits legally authorizes the plants to use fuels with higher heat content value having higher emission rates. See [Jaraite and Maria (2010)]. Details of the literature used are reported in Table 4 in appendix.

Chapter.3 Energy Sector Of Pakistan

Energy is one of important determinants of development, it is indispensable for not only the continuation of life but also the development of the quality of life and enrichment of cultures, civilizations owes much to adequate supply of energy. The per-capita consumption of energy reflects the wellbeing of a nation. The countries with greater HDI, have higher per-capita energy consumption.

Pakistan is an energy deficient country, and facing daunting task to meet the growing energy demand which is projected to reach 129 million tones of oil equivalent (MTOE) in next 15 years. [See Pakistan (2008)]. The robust economic growth and rise in per-capita income increased the energy demands sharply; on the other hand energy supply remained too short to meet the oversized demand due to lack to exploitation and exploration of new energy resources.

Fig 3.1
Per Capita Availibility of Energy in Pakistan



Source: Energy Year Book 2010

Energy sector faced constrains and concerns in the last decade. A sharp increase in prices in global energy markets laid an upward pressure on costs of energy. Increase in oil prices tapered per-capita energy availability in Pakistan. It dropped from 0.4 TOE in 2007 to 0.28 TOE (Tons of Oil Equivalent) in 2010. Moreover, the rising prices of oil in international markets caused large domestic shortage of electricity generation and lack of hydropower infrastructure added to the severity of the crisis. This energy shortage had its adverse impacts on economy, and the energy crisis caused 2 percent loss in GDP during 2009-2010.

3.1 Electricity in Pakistan

Pakistan inherited only two power plants with generation capacity of 60 MW, with a per annum growth rate of 7.2percent the generating capacity of system stood at 19566 MW in 2010. The share of hydroelectric generation declined from 69percent in 1960 to 33percent in 2008 accordingly the proportion of thermal generation increased from 30.9percent to 66percent See [JV (2011)]. The state policies encouraged thermal power generation despite having sustainable and environment friendly option of hydroelectric power generation.

Policies and principles of power generation in Pakistan are laid and executed by Federal Ministry of Water and Power, electricity market in Pakistan could be sorted into semi-privatized and semi-public vertically incorporated sector. The country has total installed capacity of 19522 MW. The public sector includes WAPDA and KESC. KESC was established in 1931 with an aim to provide electricity for Karachi and its surroundings. It generates, transmits and distributes in an area of 6,000 square kilometers, to 1.7 million customers independently.

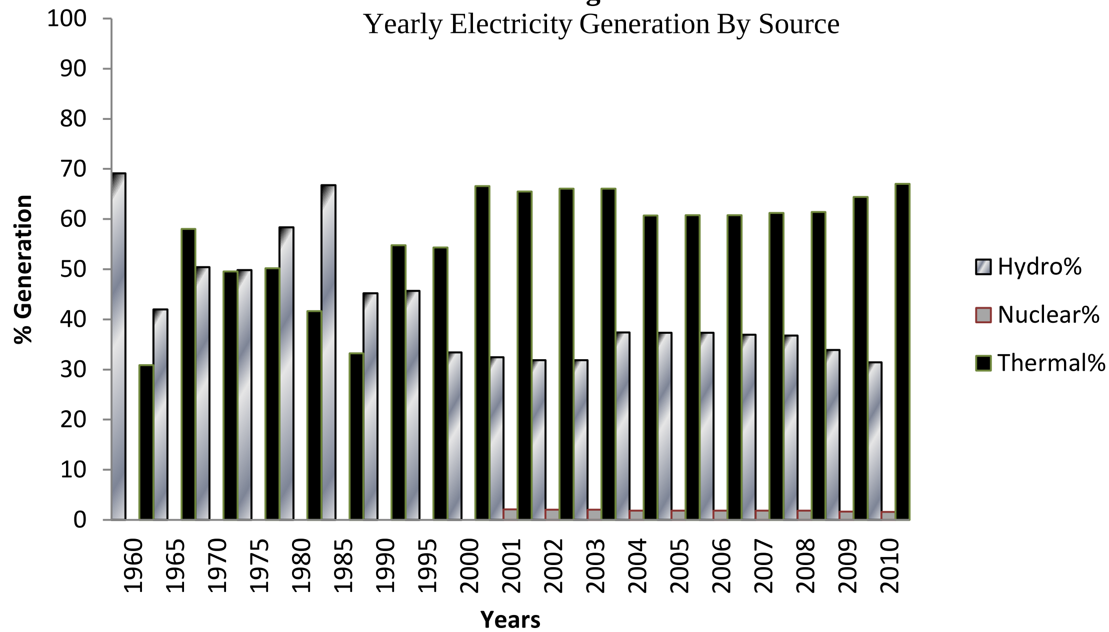
In 1958 WAPDA was establish, for generation, transmission and distribution of electric power along with flood control and drainage across the country. WAPDA owns more than 58percent of total installed capacity, and hands round about 88percent of consumers. After privatization, WAPDA has been dissolved into eight electric supply companies. Former Area Electricity Boards, that were governing the distribution and supply, expansion and construction, and operation of distribution systems, were restructured into distribution companies (DISCOs) along with three-generation companies (GENCOs), and National Transmission and Dispatch Company have been created.

Pakistan Electric Power Company is the entity to manage and regulate the distribution and generation companies. For fair promotion of competition in electricity market, and to protect the rights of consumers the Government of Pakistan has acted out “Regulation of Generation, Transmission and Distribution of Electric Power regulation Act, 1997”. Under which National Power Regulatory Authority issues license of generation, regulates and monitors the transmission and distribution of electricity, determines the power tariff and prescribes the standards.

In last three decades, Pakistan’s installed generating capacity increased fourfold. Until the introduction of 1994 energy policy, Hydropower was contributing nearly 45percent of all electricity generated in the country but in 2001 the share dropped to 26percent only and the energy mix changed with a ratio 0f 26:73.

Fig 3.2

Yearly Electricity Generation By Source



Source: Energy Year Book, 2010

3.2 Energy and Economic Growth in Pakistan

Before the two oil crises of 1970 energy hadn't any noteworthy status in the frameworks of economic development; it was thought to be merely an intermediate output, economic development was thought to be dependent upon the major inputs of land, labor and capital. Energy didn't appeared explicitly in any growth model. See [Varinder (2011)].

Rising prices of energy and mounting imports bill after the oil crises of 1970, led the economists to consider the significance of energy in the economic growth. Economist started to believe on an implicit relation between energy and economic development as energy shortages started to hamper the pace of economic growth and slowed down the role of other factors of development.

The literature includes diverse views, concerning the relation between economic growth and energy consumption. It has been widely argued that increasing energy consumption triggers development, on the other hand energy is thought to have a neutral and limiting relation to economic development, however impact of energy use on economic growth depends upon the stages of growth and upon the structure of the economy.

To gauge the impact of energy on economic development energy growth causality studies have been carried out. In Pakistan studies show that energy shortages may hamper the pace of economic growth. The growth rate of economy can be heightened via technology. Technology will ensure sufficient and efficient energy supply to manufacturing and domestic sectors of the economy. Moreover through innovations and adaptation technology will ensure efficient consumption which is far more important than generation. The empirical studies show that the increased use of energy has favorable impacts on economic growth, and improves the overall life standard. The rural electrification in Pakistan has enhanced the quality of life and has increased the productivity and increased the work hours of labor. The energy shortfall has hit industrial sector severely as industrial sector is most energy intensive sector. See [Siddiqui (2004)].

Electricity consumption leads to economic growth without any feedback. Increase in electricity consumption ensures economic prosperity for current as well as future generations. However, in case of Pakistan, economic growth is restrained by poor management, underdeveloped power infrastructure and consciously engineered power outages; widening the chasm between energy demand and energy supply resulting superfluous increase in power prices. That not only limits the accessibility to energy but it may get in the way of development. [Hye (2010)].

The share of electricity and gas distribution in GDP is decreasing annually, while the share of labor force in electricity and gas distribution sector is increasing. Despite of addition of labor force the performance of the electricity and gas sector in GDP formation is not up to the mark. Graph 3.2 depicts the declining share of GDP with increase in active labor force in it.

Fig 3.3

Labor Force and GDP Share of Electricity and Gas Distribution

Source: Economic Survey of Pakistan Various Issues

Moreover the sector growth rate is distressingly low, from a growth rate of 10.1percent in 2001, within short span of time the growth rate of electricity and gas distribution was on -26.6percent in 2007 and -22.0percent in 2008. The decline in growth rate might be following inflow of FDI. The net inflow of FDI in the power sector declined from 320.2 million US $ in 2004, to 53 million US $ in 2008.

Chapter.4 Data and Methodology

4.1 Inefficiency Stochastic Frontier Model

The study has employed the stochastic frontier model for the panel data introduced by Batese and Coelli (1993). Following model is assembled following Baten, Kamil and Haque (2009);

$$Y_{it} = \exp(\beta X_{it}) + \zeta_{it} - \xi_{it} \qquad i = 1, 2 \ldots. N. \; t = 1, 2 \ldots N \qquad \ldots\ldots\ldots\ldots \quad (1)$$

Where; Y_{it} is the output of the i^{th} power plant in t^{th} period; X_{it} is a vector of inputs and other explanatory variables related to i^{th} power plant. β is a vector of unknown parameters to be estimated by the frontier analysis. ζ_{it}'s are the random variables which are assumed to i.id $N(0,\sigma_{\zeta}^2)$ and ζ_{it}'s are independent of ξ_{it}; ξ_{it}'s are positive random variables associated with technical inefficiency of production, which are assumed to be independently distributed as truncations at zero of the $N(\mu,\sigma_{\xi}^2)$ distribution; where $\mu=z_{it}\delta$ and variance σ_{ξ}^2; z_{it} is a $1xp$ vector of explanatory variables associated with inefficiency of power plant over time, and δ is a $1xp$ vector of unknown parameters. The Stochastic production function in equation (1) specifies the coefficients in terms of original production values and units. However the technical efficiency effects ξ_{it}'s are assumed to be a function of the selected explanatory variables, the z_{it}'s and an unknown vector of coefficients**.**

The technical inefficiency effect ξ_{it} in stochastic frontier according to Batese and Coelli (1993) from (1) is specified in equation (2),

$$\xi_{it} = z_{it}\delta + \tau_{it} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (2)$$

Where; the random variable τ_{it} follows truncated normal distribution with mean zero and variance σ^2, in such a way that the point of truncation is $-z_{it}\delta$, such that $\tau_{it} \geq -z_{it}\delta$. These assumptions are consistent with ξ_{it}'s being positive truncation of $N(z_{it}\delta, \sigma_{\xi}^{2})$ distribution.

The method of maximum likelihood is recommended for simultaneous estimation of parameters of Stochastic frontier (1) and the model (2) for technical efficiency effects. The likelihood function is expressed in terms of variance parameters,

$$\sigma^2 = \sigma_{\zeta} + \sigma_{\xi}^{2}$$

After estimating ξ_{it}, the technical efficiency of the i^{th} power plant at t^{th} observation is

$$TE_{it} = \exp(-\xi_{it}) = \exp(-z_{it}\delta - \tau_{it}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3)$$

4.2 Specification of Model for SFA and Technical inefficiency

The following specified functional forms of stochastic frontier production functions were estimated to evaluate the selected plants.

$$\ln(PG_{it}) = \beta_0 + \beta_1 T + \beta_2 OS + \beta_3 lnAge_{it} + \beta_4 lnCSN_{it} + \beta_5 lnCE_{it} + {}^1/_2 \left(\beta_{11} T^2 + \beta_{22} OS^2 + \beta_{33} lnAge_{it}{}^2 + \beta_{44} lnCSN_{it}{}^2 + \beta_{55} lnCE_{it}{}^2\right) + \beta_{12} T^* OS + \beta_{13} T^* lnAge_{it} + \beta_{14} T^* lnCSN_{it} + \beta_{14} T^* lnCE_{it} + \beta_{21} OS^* lnAge_{it} + \beta_{23} OS^* lnCSN_{it} + \beta_{24} OS^* lnCE_{it} + \beta_{31} lnAge_{it}{}^* lnCSN_{it} + \beta_{32} lnAge_{it}{}^* lnCE_{it} + \beta_{41} lnCSN_{it}{}^* lnCE_{it} + \zeta_{it} - \xi_{it} \quad \ldots\ldots.\ldots\ldots (4)$$

$$\ln(PG_{it}) = \beta_0 + \beta_1 T + \beta_2 OS + \beta_3 lnAge_{it} + \beta_4 lnCSN_{it} + \beta_5 lnCST_{it} + \beta_7 lnCE_{it} + {}^1/_2 \left(\beta_{11} T^2 + \beta_{22} OS^2 + \beta_{33} lnAge_{it}{}^2 + \beta_{44} lnCSN_{it}{}^2 + \beta_{55} lnCST_{it}{}^2 + \beta_{66} lnCE_{it}{}^2\right) + \beta_{12} T^* OS + \beta_{13} T^* lnAge_{it} + \beta_{14} T^* lnCSN_{it} + \beta_{14} T^* lnCE_{it} + \beta_{21} OS^* lnAge_{it} + \beta_{23} OS^* lnCSN_{it} + \beta_{24} OS^* CST_{it} + \beta_{25} OS^* lnCE_{it} + \beta_{31} lnAge_{it}{}^* lnCSN_{it} + \beta_{32} lnAge_{it}{}^* lnCST_{it} + \beta_{34} lnAge_{it}{}^* lnCE_{it} + \beta_{41} lnCSN_{it}{}^* lnCST_{it} + \beta_{42} lnCSN_{it}{}^* lnCE_{it} + \beta_{51} lnCST_{it}{}^* lnCE_{it} + \zeta_{it} - \xi_{it} \quad \ldots\ldots\ldots\ldots\ldots \ldots\ldots \ldots\ldots\ldots\ldots.. \ldots\ldots.. \ldots\ldots.. \ldots\ldots.. \ldots\ldots. (5)$$

Where PG_{it} is power generated by the i^{th} power plant, in the t^{th} year, T is the Time in period taken as input variable to capture the plant specific effects on the efficiency.CSN is the amount of fuel consumed by the power plant to generate PG amount of electricity. CST is the per unit cost of the PG, it includes labor, capital, maintenance and transportation cost of PG in t^{th} year's, CE are carbon emission emitted by a power plant by combusting CSN amount of fossil fuel, to generate PG. Age depicts the age of i^{th} power plant, in the t^{th} year, OS represents the ownership of the i^{th} plant. ζ_{it} is the disturbance term with normal properties as explained, ξ_{it} is the plant specific inefficiency component. T is the time variable that accounts for Hicksian neutral technological change that also specifies the magnitude of inefficiency effects that may change linearly with respect to time period.

The null hypothesis of existence of efficiency is defined as

$H_0 : \gamma = 0$

Where γ is the variance ratio, which explains the total variation in the power generation from the frontier level of power generation which we had already defined as efficient level of power generation. γ is defined as $\gamma = \sigma_{\xi}^{2} / (\sigma_{\xi}^{2} + \sigma_{\zeta}^{2})$. Incase σ_{ξ}^{2} is zero the null hypothesis will be accepted, indicating that ξ_{it} should be removed, leaving no room for Maximum likelihood estimation for parameters, rather the parameters should be estimated consistently estimated using ordinary least square (OLS).

4.3 Data

Data on the required variables of thermal plants have been taken for the period of 2006-2010,from various issues of State of Industry Report yearly published by National Electric Power Regulation Authority (NEPRA). The data included thirty two power plants from both public and private sector operating on gas, furnace oil and coal and that’s makes total 160 observation in the study. The study intended to include Fixed cost as explanatory but due to non-availability of the data on Fixed costs of thermoelectric power plants the study leaves scope for further research. However the emission from thermal power plants were quantified following IPCC Draft guidelines for National green house gas Inventories 2006. Input and Output variable are shown in the Table 4.1.

Table 4.1
Variable Used in the Models

Input Parameter	**Unit**
Fuel Consumption	TOE
Fuel Type	Dummy Variable
Age	Years
Per unit Cost	Pak Rupee
Ownership	Dummy
Time	Dummy
Output Parameters	**Unit**
Electricity Generated	MWh
CO_2 emissions	Tones

4.4 Emission from Thermal Energy Sector

Combustion of stationary fossil fuel in thermoelectric power plants results in emission of Green house gases, like Carbon dioxide, Methane, Sulfur dioxides and Nitrous Oxide. Anthropogenic activities hastened the growth rate of atmospherics concentration of GHG inventories since 1950, therefore quantification and reporting of GHG inventories is imperative. [Khan and Baig (2003)] quantified GHG emission in Pakistan using both Reference Approach and Source Category Approach following IPCC Draft guidelines for National green house gas Inventories 1995. The study found that energy sector is most GHG emitting sector, in 2000, it contributed 86064.79 Gg of CO_2. The study observed that thermal power plants biggest source of GHG emissions and thermal power plants in Pakistan tend to grow by rate 9.7 that are leading to 3.7 percent growth rate of fossil fuel consumption. The study found 27.63 percent increase in CO_2 emissions from the energy sector for the period 0f 1995-2000.

There are two main approaches to record CO_2 emissions from stationary combustion sources. Direct measurement method and Analysis of fuel input method. Fuel analysis is an approach in which we follow the mass balance principle, and direct measurement method is made by using Continuous Emission Monitoring Systems. See [IPCC (2006)]. Despite the fact that CEMS is most accurate and precise method of estimating emissions from the fossil fuels the study will use Analysis of fuel input method to quantify the emissions from thermoelectric power plants due to lack of emission monitoring system on the plants. The emission monitoring devices, installed on the smokestacks of furnaces or boilers can record the emissions emitted by certain type of fuel. Pakistan being a developing country lacks such facilities so we have to adopt fuel analysis method with an accuracy level of 95percent.

Estimation of CO_2 emission by fuel analysis approach involves determining carbon content of fuel combusted; the carbon content is then used to quantify the CO_2 emissions due to combustion of a certain fossil fuel. The carbon content factors used in Fuel Analysis approach must be based upon the energy unit, neither mass units nor volume units could be used in this approach, because carbon content factors based on energy units are less variable then carbon content factors per mass or volume units. [See IPCC (2006)]. Moreover the energy value of fuel depends upon the amount of carbon in the fuel rather to mass or volume of the fuel. The Equation (12) is an overview of the default fuel analysis method as in [IPCC (2006)]. Fuel types and their respective heat contents, carbon content coefficients and fraction-oxidized factors are listed in Table 4.2. The emissions are quantified after conversion of data onto required units.

$$Emissions = \sum_{i=1}^{n} QF \times HC \times CT \times FO \times 0.001 \qquad (12)$$

where:

QF = Mass or Volume of Fuel Combusted

HC = Heat content of Fuel (energy/ mass or volume of fuel)

CT = Carbon Content Coefficient of Fuel Type

FO = Fraction Oxidized of Fuel

The fraction 0.001 is multiplied to the equation to obtain CO_2 emission in tons.

Table 4.2

CO_2 Emission Coefficients

Fossil Fuel	Default High Heat Value	Default CO_2 emission factor	Fraction Oxidized
Natural Gas	0.001029 (btu/scf)	53.02 (kg C/mmBtu	1.0
Furnace Oil (Fuel Oil #6)	0.15 (mmbtu/gallon)	75.1 ((kgC/mmbtu)	1.0
Sub-bituminous Coal	14.21 mmbtu/ton	96.36 (kgC/mmbtu)	1.0

4.5 The Shadow Prices of CO_2

The study attempts to estimate shadow price of CO_2 emitted to generate single unit of electricity generated by combusting fossil fuels in it. Distance function is widely used in literature to estimate the abatement costs, and shadow prices of the pollutants; that haven't any market to be priced. The distance function shows the relative distance between a pragmatic output input combination and the production possibility curve.

In the realm of literature we can find three types of distance functions, which have been employed to price the non-priced and undesirable outputs. Shepherds output distance function, the directional output distance function and the input distance function. Input distance function proportionally reduces the inputs keeping the vector of output constant; on the other hand output distance function maximizes the outputs proportionally. Input and output distance functions are based upon the notion of return to the scale, that depends upon the technology; if the technology operate on the principle of constant return to scale the input and output distance function will be equal. However the foundation of output distance function lies in the expansion of output, while input oriented distance function tends to minimize costs. See [Hailu and Veeman (2000)].

The study following See [Hailu and Veeman (2000)] the study estimated shadow prices CO_2 for the thermoelectric power plants. Assume a technology that produces a vector of good outputs y_g and a vector of bad output y_b. The technology is defined as

$$T = \left((x, y_g, y_b): x\ produces\ , y_g, y_b\ \right).$$

Employing this technology, we can define input oriented DF. The input distance function proportionally reduces all the inputs spend in the technology to pull off maximum output. Now we can rewrite the technology through the output scenario$P(x) = [(y_g, y_b): (y_g, y_b) \in T.$

Then the input oriented Distance function could be defined as

$$DF(x, y_g, y_b) = \ f\ \lambda: x/\lambda\, , y_g, y_b \in P\ (x)$$

It should be kept in mind that the production of bad output and good output linked together, if $(y_g, y_b) \in P\ (x)$ and $y_g = 0$, then $y_b = 0$. IDF could take maximum value of 1, which is the efficient production of a technology and any value higher than 1 means that the firm is employing higher amount of inputs. The technically efficient level of IDF is

$$\boldsymbol{T_E = \frac{1}{DF(x, y_g, y_b)}}$$

Table 4.3 briefly describes the variables used to estimate the shadow prices of CO_2 for thermal power generation in Pakistan.

Table 4.3

Input Output Variables

Input Variables	Fuel Combusted (Kg), Per Unit Cost
Output Variables	CO_2 Emitted, Power generated

4.5 Limitations of the Study

Efficiency is a time variant notion, and should be analyzed in a long horizon of time, but the study was limited to a shorter period due to non-availability and inaccessibility to the data. In the time series data the variation and alterations in the efficiency could be recorded in the long run, and could be handy in policy making decisions. Moreover the study used Fuel analysis approach to measure CO_2 emissions from the thermoelectric power plants, and the Higher Heat Factors and CO_2 emission factors may vary due to different technologies of extraction, but the study assumed constant Higher Heat Factors and CO_2 emission factor for each type of fuel.

Efficiency is a dual concept, efficiency of production is one side of the coin, and the other one is the efficiency in consumption, but limited resources and time restricted the study to production efficiency only. Moreover the mechanical aspects of the plants are due important in efficient production, but information on installation and performance of thermoelectric power plants is not available therefore the study uses time as proxy for the technical aspects.

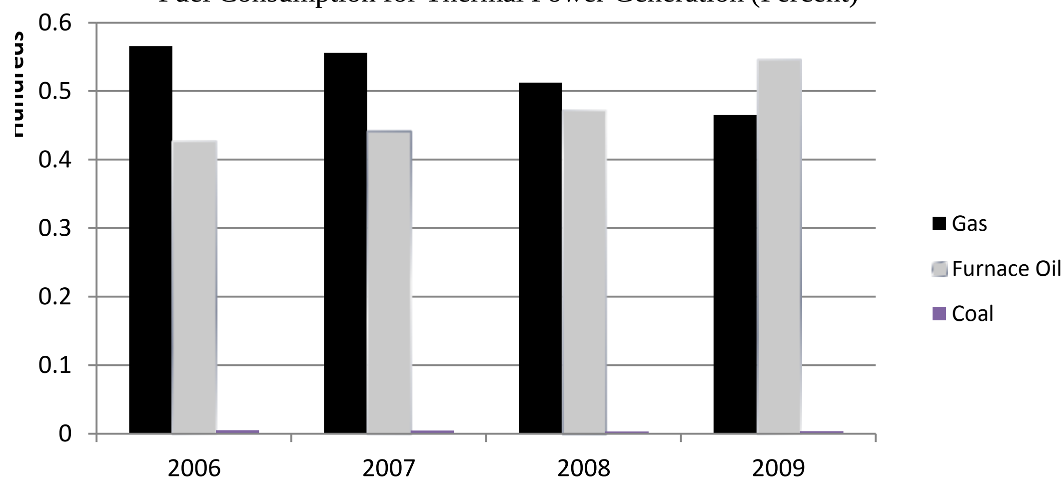
Chapter 5. Descriptive Statistics

5.1 Fuel Mix

Significant changes have taken place in thermal electricity production sector during the period of 2006-2010. Especially in fuel mix, due to variation in fuel prices of gas and petroleum, and due to supply shocks in particular. In 2006 the Natural Gas consumption by thermal power plants was 8640101 TOE , about 56percent of the fuel consumed by thermoelectric power plants, but in 2010 it decreased to 7106962 TOE, about 46percent of total fossil fuels consumed by the thermoelectric power plants. While the deficit of Natural Gas was fulfilled by Furnace oil. Consumption of furnace oil by the thermal power plants was 6521503 TOE in 2006 and it increased to 8339330 TOE in 2010. The Fig 5.1 illustrates the state of different fossil fuels graphically.

Fig 5.1

Fuel Consumption for Thermal Power Generation (Percent)

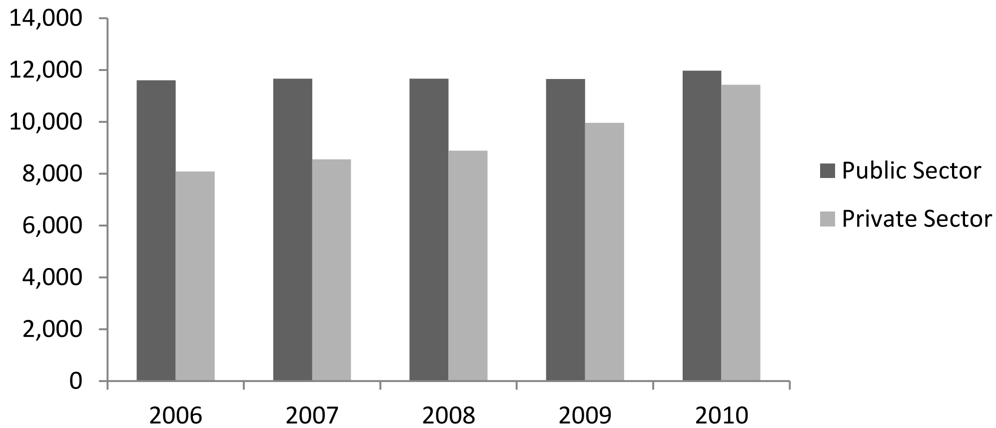


5.2 Sector vise generation

Generation by public sector decreased with a rate of 2percent, in 2006 public sector entities produced 59percent of the generated power in the economy that kept decreasing, though with slow pace, in 2010 it was 11,979 MW 51percent of total generated power. Whereas this gap was filled by private sector, from 41percent in 2006 the private sector in 2010 produced 49percent of the total electricity generated.

Fig 5.2

Generation Capacity by Sector (MW)



5.3 Thermal Electricity Generation by Fuel Type (GWh)

The total electricity generated by combustion of Gas sources decline though out the period, 14percent decrease in generation through Gas is evident from table 4.1. In 2006 37000 GWh electricity was generated by Natural gas, which shriveled to 29000GWh in 2010. However Generation by Furnace Oil kept increasing to fill the gap produced by decline in generation via gas combustion. Generation through Coal sources remained constant with minute alterations.

Table 5.1

Thermal Electricity Generation by Fuel (GWh)

Source Fuel	2006		2007		2008		2009		2010	
	Total	Share	Total	Share	Total	Share	Total	Share	Total	Share
Gas	37006	58.2	35624	54.2	39108	60.4	32647	47.7	29118	44.7
Furnace Oil	26449	41.6	29928	45.6	25513	39.4	35641	52.1	35847	55.1
Coal	136	0.2	136	0.2	113	0.2	139	0.2	131	0.2

5.4 Selected Power Plants

This section deals with the selected thermoelectric power plants of Pakistan. Data on 32 plants have been collected, 13 of which operates on Furnace Oil, 18 on Natural Gas and 1 on

Coal. 13 Out of 31 thermoelectric plants are operated by public entities while 18 plants were being operated by Public sector, Table 5.2 gives an account of the power plants.

Table 5.2

Selected Power Plants

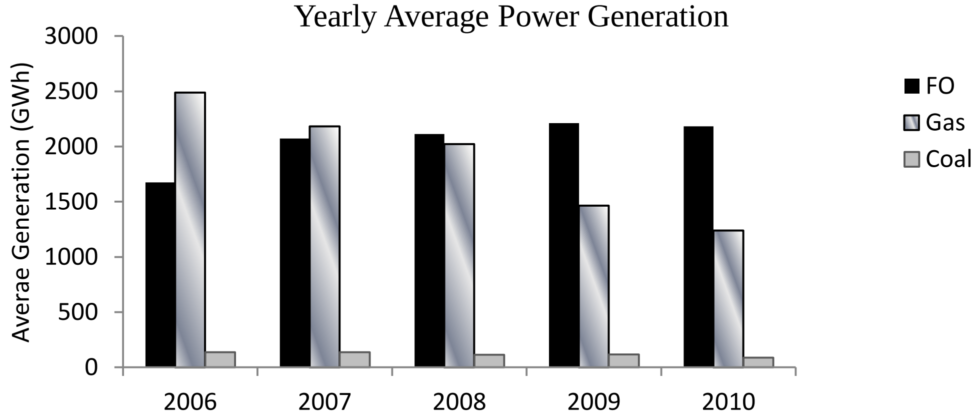
Plant	Source Type	Sector	Commissioning Date	Installed Gen Capacity (MW)
GTPS Quetta	Natural Gas	Public	1984	35
Fauji Kabirwala	Natural Gas	Private	2000	48
GTPS Shahdara	Natural Gas	Public	1969	59
GTPS Korangi	Natural Gas	Public	1959	80
GTPS Site	Natural Gas	Public	1979	100
Tapal Energy	Residual Oil	Private	1997	126
Habibullah	Natural Gas	Private	1999	129
TPS Multan	Residual Oil	Public	1960	130
Kohinoor Energy	Residual Oil	Private	1997	131
SPS Faisalabad	Residual Oil	Public	1967	132
Saba Power	Residual Oil	Private	1999	134
Japan Power	Residual Oil	Private	2000	135
FBC Lakhara	Coal	Public	1987	150
NGPS Multan	Natural Gas	Public	1963	195
TNB Liberty Power	Natural Gas	Private	2001	235
GTPS Faisalabad	Natural Gas	Public	1975	244
TPS Jamshoro	Residual Oil	Public	1990	250
GTPS Kotri	Natural Gas	Public	1977	316
Aes PakGen	Residual Oil	Private	1998	365
KAPCO Kot Adu	Residual Oil	Private	1987	424
Rousch Power	Natural Gas	Private	1999	450
Uch Power	Natural Gas	Private	2000	586
GTPS Jamshoro	Natural Gas	Public	1990	600
GTPS Guddu (5-13)	Natural Gas	Public	1985	640
KAPCO, Kot Addu	Natural Gas	Private	1987	1215
TPS Bin Qasim	Residual Oil	Public	1983	1260
HUBCO	Residual Oil	Private	1996	1292
TPS Muzaffargarh	Residual Oil	Public	1993	1350
GTPS Muzaffargarh	Natural Gas	Public	1993	1350
TPS Guddu (1-4)	Residual Oil	Public	1974	1655
TPS Bin Qasim	Natural Gas	Public	1983	1260
AES LAL PIR	Residual Oil	Private	1997	365

5.3 Power Generation

Generation by Furnace Oil has significantly increased to cater the supply shortage, caused due to decrease in generation through the combustion of gas. The average generation by Furnace oil is mounting as compare to gas and coal. It seems that generation by Furnace oil is replacing by gas. Fig 5.3 shows the average generation by thermoelectric plants through Furnace Oil, Gas and Coal.

Fig.5.3

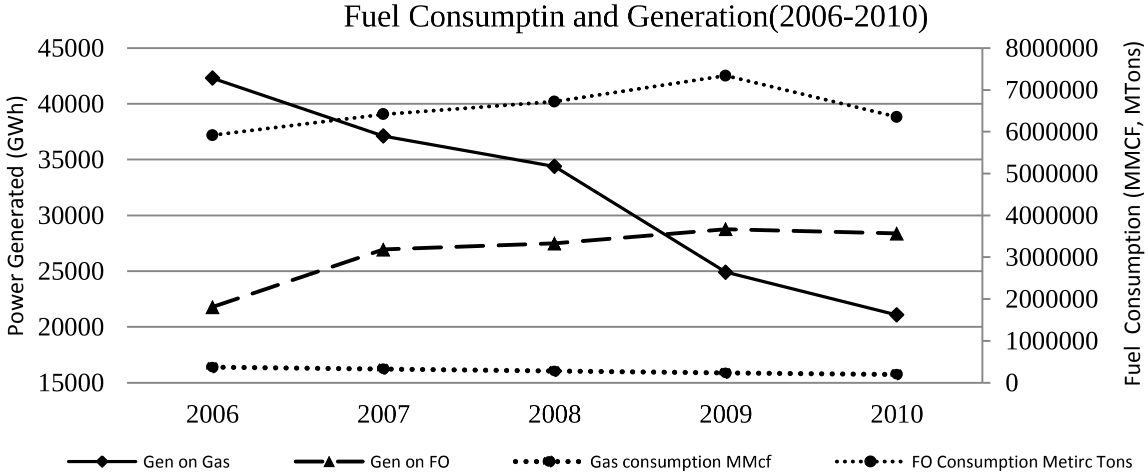
Yearly Average Power Generation



The decreasing trend of generation on Natural gas is evident from the Fig 5.4, both the production on gas and consumption of natural gas are declining while power generation by Furnace Oil and its consumption is showing an increasing trend.

Fig. 5.4

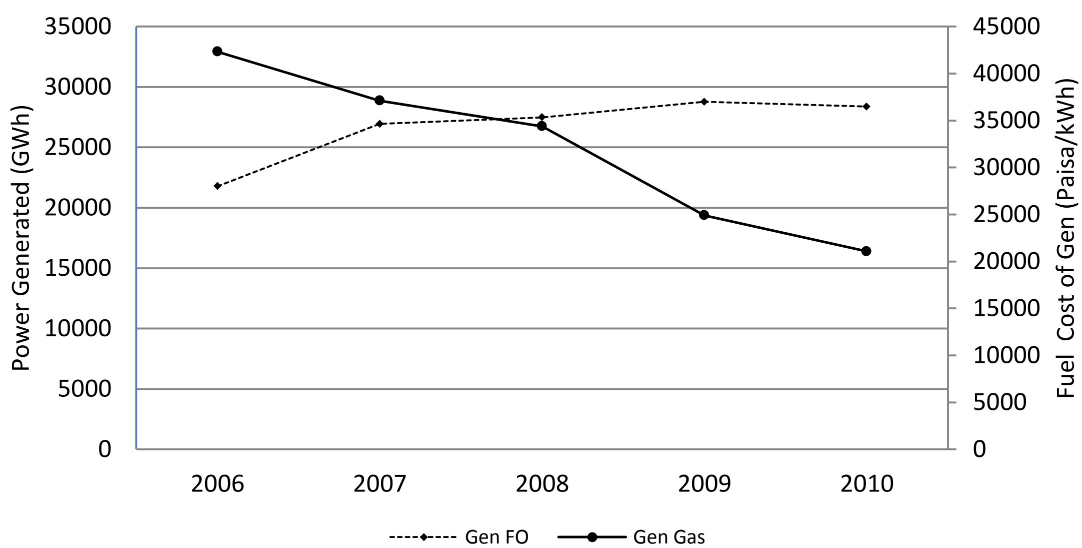
Fuel Consumptin and Generation(2006-2010)



5.6 Scale Effects

The generation of electricity follows increasing returns to scales, as the amount of power generation increases the cost of production decreases and as the amount of power generation decreases the cost of production starts increasing. In 2006 the power generated on gas was 42316GWh, with variable cost of 7384.55 Paisa/kWh, which increased to 14751.84 Paisa/kWh as the generation on gas was cut halved into 21075.54GWh. Fig 5.5 records the scale effects of plants operating on Natural Gas.

Fig 5.5
Scale Effects in Thermal Power Generation (2006-2010)



5.7 Emission Per unit of Generation

On average gas fueled power plants emit less CO_2 per GWh generation of electricity. Fuel Oil is slightly more polluting fuel and Coal is most emitting fuel as compared to gas and oil. Oemission rate depends upon the high heat value and default CO_2 emission factors, and coal has the highest High heat value and CO_2 emission factor. Table 5.3 shows emissions from the three technologies of power generation.

Table 5.3

Emissions per Unit Generation (Tons CO_2/gWh)

Fuel Type	2006	2007	2008	2009	2010
Gas	55.11441	3.181793	3.187945	2.974488	3.080133
Furnace Oil	48.08524	47.83038	47.37606	48.33181	48.09894
Coal	2018.159	1993.547	1792.08	1803.443	1825.74

5.8 Consumption per gWh

Table 5.4 shows average consumption of different power plants per unit generation of electricity. On average gas has highest consumption of unit fuel per gWh generation of electricity. As gas has the lowest heat values so higher amount of gas is combusted to generate one GWh electricity.

Table 5.4

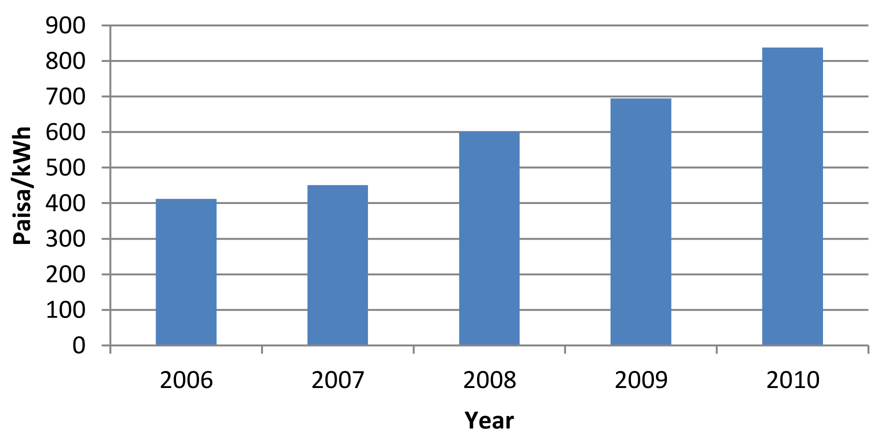
Fuel Consumption Per gWh

Fuel Type	2006	2007	2008	2009	2010
Natural Gas (MMCFT)	0.0951631	1.6483965	1.6452152	1.7632805	1.7028019
FO (Ton)	0.0041641	0.0041774	0.0042175	0.0041341	0.0041541
Coal (Ton)	0.0008293	0.0008395	0.0009339	0.0009280	0.0009167

5.9 Average Cost by Fuel Type

Fig. 5.6

Annual Per unit Average Cost of Generation by Natural Gas



The average cost of generation by gas increased 200percent during the period of study. In 2006 per unit average cost of generation through natural gas was 411 paisa/kWh which increased to 837 paisa/kWh. The same trend is followed by Furnace oil and coal. Fig 5.5, Fig 5.6 and Fig 5.7 portrays the trend of rising average per unit costs of Natural gas, furnace oil and coal fired plant in the thermal sector of Pakistan.

Fig. 5.7

Annual Per unit Average Cost of Generation by Furnace Oil

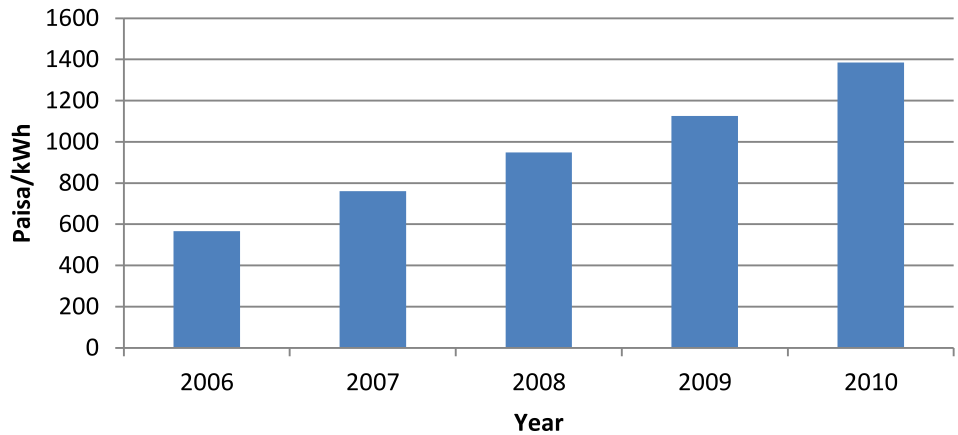
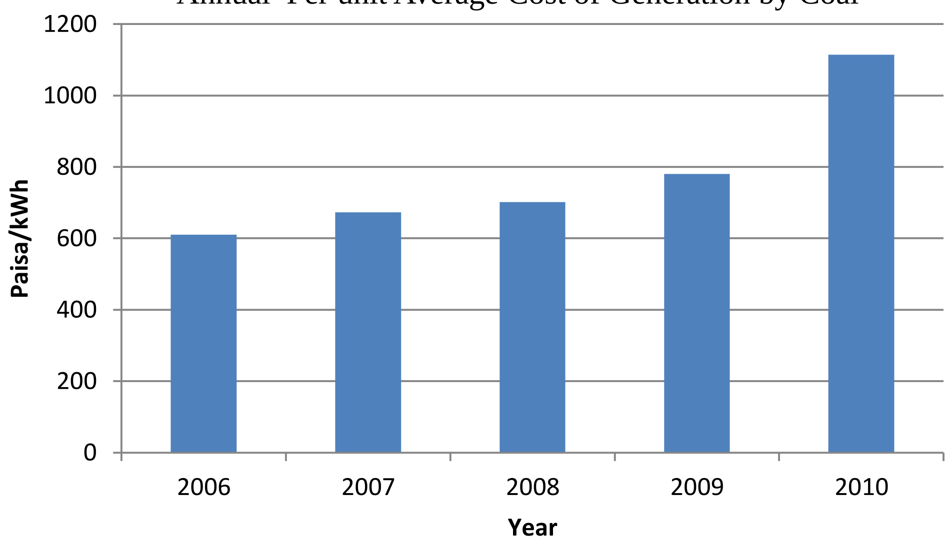


Fig. 5.8

Annual Per unit Average Cost of Generation by Coal



Chapter.6 Results

The translog production frontier of panel; comprising of the thermal power generation data of 32 plants for the period of 2006-2010 was estimated on the methodology drafted above. The best specification for the production function for the panel data was selected after the performing the generalized likelihood ration (LR) hypothesis test defined as

$$\lambda = -2\{ln[L(H_o)/L(H_1)]\} = -2\{ln[L(H_o)] - ln[L(H_1)]\}$$

Where, $ln[L(H_o)]$ is the value of LR function for the stochastic frontier estimated, and $ln[L(H_1)]$ is the value for the 32 stochastic production functions estimated separately.

The results of OLS and MLE for the Translog production are reported in Table 6.1

Table 6.1

Regression and Frontier Results for Power Generation (2006-2010)

	Regression (OLS)		**Stoch. Frontier**	
	Coeff	Std.Error	Coeff	Std.Error
Constant	-261.24	96.916**	-208.38	89.38***
Ownership	0.514	0.124*	0.459	0.110***
Plant Age	0.171	0.0217	-0.260	0.024**
Fuel Consumption	0.594	0.062***	0.715	0.072***
Time	0.1298	0.124	0.104	0.044***
CO2Emissions	0.392	0.047***	0.294	0.04***
R^2	0.83		LR	172.57
$\bar{R}^2$	0.82		δ^2	1.08
F	150.95			
N	160		N	160

. *, **, *** indicates significance at the 90percent, 95percent, and 99percent level, respectively.

The values of log likelihood functions for ordinary least squares and maximum likelihood estimates allows to test if the technical inefficiency exist in the model or not, if the technical inefficiency does not exists in the model there will be no difference in the parameters of both the

MLE and OLS. The estimated results show that all the explanatory variables that include Ownership, Plant age, Fuel consumption CO_2 emissions and Time are statistically significant. Time is taken as dummy for each year, that captures the firm specific time variant effects in Power generation. The results show that the input variables significantly impacts the power generation. However Plant age shows dubious behaviors, it changes both its significance and elasticity differently in MLE estimation and OLS estimations.

The second model included the per unit variable cost of the power generation, the results of the model 2 are shown in Table 6.2

Table 6.2
Regression and Frontier Results for Power Generation (2006-2010)

	Regression (OLS)		**Stoch. Frontier**	
	Coeff	Std.Error	Coeff	Std.Error
Constant	-424.84	103.98***	-356.79	95.95***
Ownership	0.617	0.123***	0.540	0.108**
Plant Age	-0.148	0.021*	-0.180	0.024**
Per Unit Cost	-0.609	0.170**	-0.595	0.159***
Fuel Consumption	0.605	0.060***	0.710	0.067***
Time	0.213	0.123**	0.180	0.040**
CO_2 Emissions	0.334	0.048***	0.248	0.045**
R^2	0.84		LR	165.85
$\bar{R}^2$	0.83		δ^2	1.02
F	137.58		λ	2.16
N	160		N	160

*, **, *** indicates significance at the 90percent, 95percent, and 99percent level, respectively.

The variable Per Unit Cost includes the cost of labor and operating cost of the plant for a single unit of electricity. As the data on labor, capital and operating cost is not available, so the study leaves opportunity for further research by including these variables. It is obvious from the results and is entwined with the theory that fuel consumption is the major impeller of generation. The results show that per unit cost of generation decreases with the as the generation raises.

The efficiency analysis reveals that none of the plants had been operating efficiently in the studied period. The mean efficiency of the observed plants was 0.54 in the first scenario, and in second scenario it was 0.55. The maximum efficiency calculated was 0.92, while the lowest was recorded on 0.13. Table 6.3 illustrates the results in brief. Table.6 in Appendix D illustrates the ranking of plant on basis of efficiency scores.

Table 6.3

Yearly Plant wise Efficiency Score (2006-2010

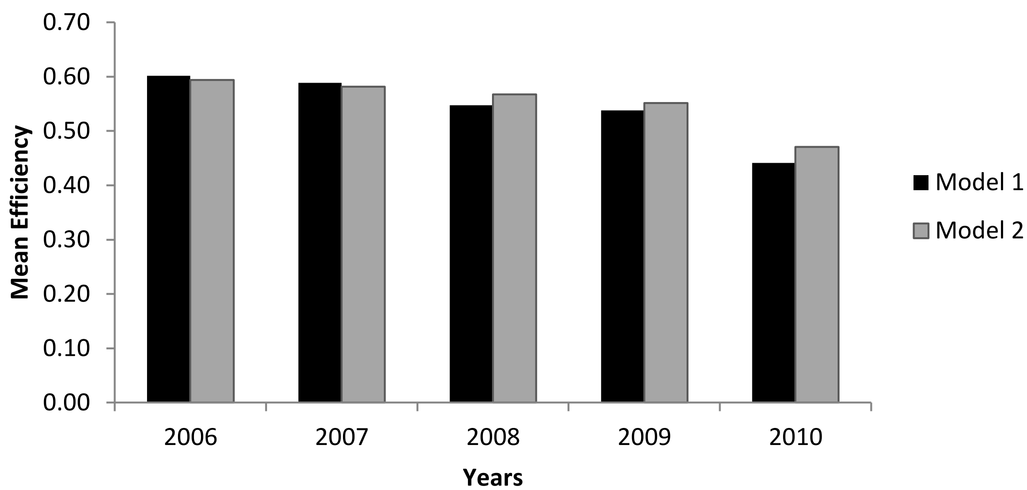
Plant	2006		2007		2008		2009		2010	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
TPS Jamshoro	0.59	0.61	0.69	0.60	0.65	0.61	0.60	0.60	0.62	0.67
TPS Guddu (1-4)	0.48	0.25	0.41	0.23	0.49	0.33	0.31	0.21	0.40	0.30
TPS Muzaffargarh	0.72	0.77	0.77	0.79	0.75	0.78	0.71	0.77	0.66	0.74
NPS Multan	0.43	0.57	0.48	0.58	0.41	0.54	0.37	0.55	0.25	0.41
SPS Faisalabad	0.46	0.69	0.57	0.64	0.52	0.61	0.49	0.60	0.37	0.47
TPS Bin Qasim	0.69	0.49	0.72	0.62	0.63	0.47	0.66	0.50	0.63	0.57
Aes PakGen	0.60	0.60	0.56	0.62	0.53	0.60	0.48	0.55	0.42	0.49
HUBCO	0.68	0.63	0.67	0.70	0.65	0.69	0.61	0.66	0.58	0.66
Japan Power	0.48	0.43	0.46	0.48	0.36	0.45	0.50	0.52	0.33	0.36
KAPCO Kot Adu	0.68	0.59	0.68	0.65	0.66	0.71	0.59	0.66	0.58	0.66
Kohinoor Energy	0.57	0.49	0.54	0.56	0.50	0.52	0.46	0.47	0.46	0.47
Saba Power	0.45	0.48	0.48	0.51	0.43	0.46	0.41	0.45	0.28	0.36
Tapal Energy	0.53	0.58	0.51	0.52	0.45	0.49	0.44	0.47	0.40	0.40
AES Lal Pir	0.55	0.47	0.55	0.51	0.51	0.48	0.48	0.48	0.40	0.44
GTPS Faisalabad	0.67	0.69	0.64	0.54	0.58	0.59	0.52	0.64	0.40	0.46
GTPS Korangi	0.53	0.48	0.46	0.43	0.44	0.46	0.43	0.35	0.13	0.13
GTPS Kotri	0.69	0.71	0.67	0.60	0.62	0.60	0.60	0.56	0.52	0.48
GTPS Site	0.54	0.51	0.49	0.47	0.43	0.47	0.43	0.32	0.44	0.43
NGPS Multan	0.48	0.50	0.34	0.56	0.27	0.49	0.37	0.58	0.13	0.30
GTPS Bin Qasim	0.80	0.82	0.78	0.78	0.76	0.76	0.74	0.73	0.66	0.72
GTPS Guddu (5-13)	0.80	0.83	0.78	0.69	0.75	0.69	0.74	0.66	0.68	0.58
GTPS Jamshoro	0.75	0.83	0.73	0.75	0.66	0.74	0.67	0.76	0.49	0.67
GTPS Korangi	0.65	0.66	0.61	0.55	0.61	0.58	0.59	0.49	0.44	0.37
GTPS Muzaffargarh	0.71	0.79	0.59	0.73	0.50	0.66	0.50	0.62	0.19	0.31
GTPS Quetta	0.36	0.32	0.39	0.33	0.35	0.37	0.31	0.31	0.31	0.30
Fauji Kabirwala	0.65	0.49	0.60	0.56	0.62	0.58	0.92	0.92	0.49	0.42
Habibullah	0.63	0.62	0.60	0.53	0.57	0.51	0.53	0.42	0.47	0.36
KAPCO, Kot Addu	0.72	0.70	0.68	0.75	0.47	0.65	0.60	0.73	0.41	0.61
Rousch Power	0.72	0.76	0.68	0.65	0.67	0.62	0.62	0.56	0.60	0.50
TNB Liberty Power	0.66	0.74	0.67	0.72	0.61	0.75	0.57	0.65	0.52	0.62
Uch Power	0.74	0.72	0.72	0.67	0.71	0.67	0.67	0.62	0.63	0.55
FBC Lakhra	0.23	0.25	0.33	0.29	0.31	0.25	0.31	0.24	0.24	0.23

Source: Author's Computation

From the Fig 6.1 we can infer that, in the earlier periods of the time span the industry showed a positive trend, with almost 50percent of the examined plant having efficiency above 0.60, while in 2010 about 50percent of the plants efficiencies were recorded below 0.40. It means that the efficiency of the thermo electric power plants is deteriorating day by day. It is also evident from Fig 6.1, that efficiency scores calculated by including per unit cost of generation, is decreasing by lower rate as compared to the efficiency score obtained by estimating Model 1. The reason is unknown as Per unit cost is a vector of different variable cost incurred in unit generation of power, so we do not know how and which variable upholds the efficiency scores in the second model.

Fig 6.1

Yearly Mean Efficiency of Thermal Power Generation (2006-2007)

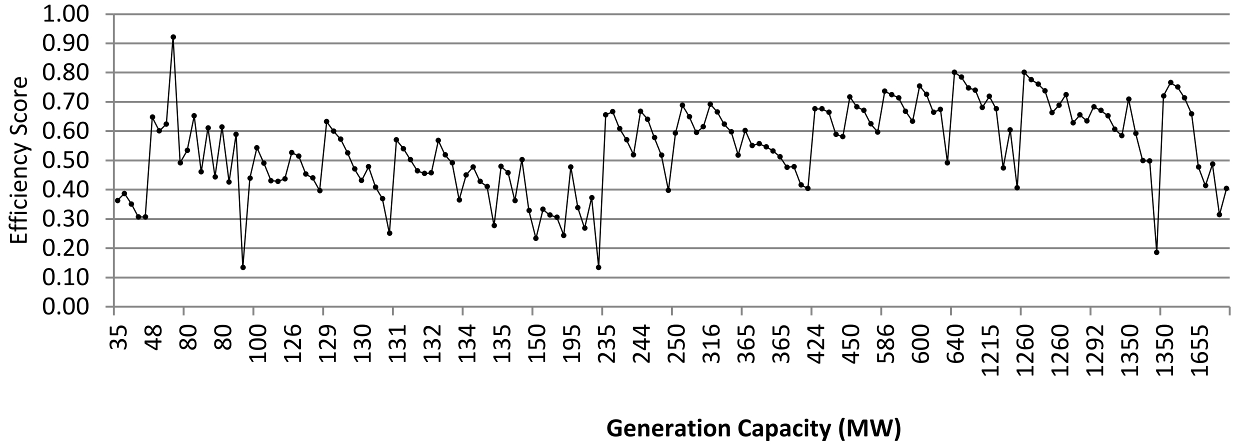


Economic theory pretenses that, plant that are operated by private entrepreneurship should be more efficient then state owned plant. The average efficiencies of privately owned power plants in both the model estimated are higher than that of the publicly controlled plants. The mean efficiency scores of publicly owned plant throughout the studied time period are 0.52 and 0.54, and that of privately operated plants are 0.63 and 0.67 respectively in the first scenario and the second scenario. Moreover a higher percentage of state operated power plants lie under the efficiency score 0.45 while the majority of private power plants achieve efficiency score higher than 0.65. In addition none of the state owned plants scored efficiency score higher than 0.70, while the private owned attained efficiency score higher than 0.90 which is almost in close proximity to efficiency. However neither a Public nor any Private owned plant was found to be operating on the efficiency frontier.

Environmental and economic efficiency of thermoelectric power plants owes much to the type of fuel combusted to generate electricity, cheaper fuels are handy for economical gain, but are the major threat to the environmental efficiency. The study found that coal is the most inefficient and uneconomical fuel, followed by residual oil and natural gas. The mean efficiency score of coal operated thermoelectric power plants were 0.29 in the first scenario, and the efficiency score got worse to 0.25 when per unit costs were introduced to model. The mean efficiency scores of residual oil fired plant remained constant at 0.52 in both the models. While the Gas fired plants scored mean efficiency score of 0.57 in the prior model and the efficiency score improved to 0.62 when the per unit costs were employed to estimate the efficiency score. Gas proved to be the most economical and eco efficient fuel for the industry.

Generation Capacity determines the power generation and consumption of the fuel, hence it direclty inflences the efficiency of the plant. The results show that plants with smaller generation capacity have lower efficiency then that of plant having higher generation capacity, and seems that the plant with higher installed capacity are experiencing economies of scale. Fig 6.2 surmises the efficiency scores and generation capacity of the analyzed plants. It reveals that with some deviations as generation capacity increases the efficiency of plants improves.

Fig 6.2
Efficiency Scores of Power Plants (Generation Capacity wise)



The study aimed at calculating the Shadow cost CO_2 for the thermal power generation. The distance function was estimated to calculate per unit Shadow cost for each plant. The study found that the average shadow cost per kWh power generation from fossil fuel is Rs. 1.549 during the period of 2006-2010. Power generation by Coal was found to be the most expensive technology and the mean shadow price for coal was Rs.7.23 per kWh, followed by Furnace Oil with a mean shadow cost of Rs. 2.96, while the mean shadow price of gas was Rs. 0.49. Table 6.4 shows the annual mean shadow prices for all the three technologies of thermal power production. See detail in Table.8 in appendix.

Table 6.4
Yearly Average Shadow Price for Thermal Power generation (2006-2010) (Rs/kWh)

	2006	2007	2008	2009	2010
Furnace Oil	2.380755	2.624177	2.780026	2.88573	3.182161
Gas	0.034149	0.037794	0.040348	0.039759	0.041342
Coal	5.362802	6.852737	8.892982	7.232659	8.286915

Chapter. 7 Summary and Conclusion

After a brief review of different perspectives, the study concluded that eco-efficient way of consumption is the sole approach of sustainable consumption therefore; economic policies must be entwined within the parameters of eco-efficiency. Pakistan is facing the shoddier power deficiency at the moment; therefore the study undertook efficiency analysis of thermoelectric power plants in Pakistan to probe into the roots of incompetence of the thermal power generation. The analysis was conducted over 95percent of the thermal power generation. Stochastic Frontier Analysis was used to evaluate the cost and environmental efficiency of the thermoelectric power plants. Moreover the study aimed to estimate the shadow prices for CO_2 emission, for thermal power generation.

The study found out that plant ages, in the case of public sector power plants in the major reason of inefficiency, it seems that no heed has been paid to mend, refurbish and enhance the Generation Capacity of the plants, therefore the rotten plants are unable compete with private thermal plant in the race of efficiency. The fuel type is strongly correlated with the efficiency; therefore the installed capacity should be enhanced only by restricting usage non eco-efficient fuels. Gas stands to be most efficient fuel in both economic and environmental approaches. Power generation by furnace oil is both environmentally and economically tolerable, however the economic cons of furnace oil are greater. It appears that furnace oil is the most expensive technology of power generation. Coal fails to fit in the eco-efficient criteria, it is too expensive fuel both economically and environmentally, the abatement cost of CO_2 emitted in a unit generation of power is three time higher than that of furnace oil and 200 time higher than that of Gas. Moreover per unit cost and per unit emission rate of coal could be lessen by research and development of coal mines, exploration and by reducing the sulfur content of coal, it can be used as an environment friendly and cheaper fuel.

It seems that ownership has a neutral role in power generation, the private plants are also incapable of operating on the efficiency frontier, however their performance is better than that of the public plant. But the public plants having greater generation capacities are efficient are perform better than small scaled private plants. Therefore it could be concluded that the public plants experiences economies of scale. The study found no significant impact of generation capacity on efficiency, or if there is any it is dubious and needs to be examined with due concern.

The study found that efforts in achieving eco-efficiency in thermal power generation is a fools errand unless the energy policies are directed towards eco-efficient criterion. No heeds have been paid to the economic returns and eco-efficiency, and the fuel mix of power generation has been diverted to the fossil fuels. Therefore the state policies must be reviewed and hydro sector must be set in motion, so the sustainable and eco-efficient power supply to the economy must be ensured.

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Appendix A

Statistics of Thermal Power Generation

Table.1
Depreciated Generation Capacity of Thermal Power Plants

Power Plants	Commissioning Year	Fuel Cost (Rs/kWh)	Installed Capacity (MW)	Present Capactiy (MW)
NGPS Multan	1958	Rs.15 to 22	260	60
GTPS Faisalabad	1975	Rs.14	100	76
SPS Faisalabad	1967	Rs.14	132	100
GTPS Kotri	1970	Rs.7	30	20

Source: State of Industry Report, 2011

Table.2
Receivables of DISCOs ending June, 2010

S.No	Category	Receivables(June 2009) Rs. In Billions	Receivables(June 2010) Rs. In Billions
1.	Federal Government, (Agencies, AJK Government and FATA	133.959	67.172
2.	Provincial Governments, Departments and Agencies	15.899	32.616
3.	Autonomous Bodies under Federal Government	0.846	0.928
4.	Private	77.763	103.350
5.	IPPs	0.084	0.092
	Grand Total	228.551	204.158

Source: State Of Industry Report 2011

Table.3
Line Losses of DISCOS

DISCOs	Actual Losses (percent)				
	2006	2007	2008	2009	2010
HESCO	36.95	35 .86	35. 06	34.7 9	33.81
PESCO	35.21	36 .06	37. 24	36.9 1	36.61
QESCO	21.56	21 .01	20. 12	20.6 8	20.41

Source: Energy Year Book 2010

Appendix B

Table.4

Literature Review

Publication	Units/Country	Methods Applied	Variables		Results
			Input	Output	
Saleem, 2005	21 Thermal Power Plants of Pakistan	Stochastic Frontier Approach Malmquist DEA	Capital Fuel Consumption Plant Factor	Electricity Generated	3 out of 21 plants were operating on efficient frontier. Significant Impact of Ownership on efficiency. Public thermoelectric Plants are more inefficient than the Private ones.
Fallahi, Ebrahimi and Ghaderi 2011	32 thermoelectric Plants in Iran	Non-Parametric DEA	Electricity Used Operational Time Fuel Labor Installed Capacity	Net Electricity	Technical Efficiency of thermoelectric Power Plants is decreasing 50percent of the subject Plants are operating below the average level.
Thakur 2006	6 Public Thermal Electricity Generation Plants	Constant Return to scale Date Envelopment Analysis	*<u>Model A</u>* Total Cost *<u>Model B</u>* Adjusted Cost Number of Employees	Energy Sold No of Customers Distribution Line Length	All the Plants were inefficient technically. Inefficiency depends upon the Size of the Plant. Cutting down the costs, may increase the efficiency.
Sarica, Or 2007	65 Thermoelectric Power Plants in Turkey	CRS DEA Method VSR DEA Method Assurance Region DEA Approach Stochastic Frontier Approach	Fuel Cost Environmental Cost GHG emissions	Electricity Production Thermal Efficiency	Environmental Cost are highly correlated with Efficiency. Significant improvements could be achieved by cutting down environmental Costs.
Eric, Darold 2009	USA	DAE Method (Material Balance Approach)	Pollution per BTU	Electricity Generated	Environmentally inefficient.
Barros, Peypoch 2007	25 thermoelectric plants in Portugal	DEA Method Simar and Wilson bootstrapped procedure Stochastic Frontier Approach	Number of Labor Physical Assets Value Operational Costs	Electricity Produced Maximum Capacity	Most of the Plants were found to operating below the Efficiency Frontier.
Adnan, Ihsan, Adnan 2010	15 Thermal Power Plants in Turkey	DEA Approach (Operational Efficiency Index) (Environmental Efficiency Index)	Fuel Cost Labour	GHG emissions	All the plants were found inefficient.
Vaninsky 2008	USA	DEA Method	Emission Rate Energy Losses	Fuel Utilization	All plants were adequately efficient.
See and Coelli 2011	Malaysia	Stochastic Frontier Approach	Capital Labor Fuel Type Fuel	Electricity Generation	Inefficiency exists in all plants

Appendix C

Emission Factors and High Heat Values of Fuels

Table.5

Default CO_2 emission factors and high heat values for various types of fuel

Fuel Type	Default high heat value mmBtu/short ton	Kg. CO_2/mmBtu
Coal and coke	25.09	103.54
Anthracite	24.93	93.4
Bituminous	17.25	97.02
Sub-bituminous	14.21	96.36
Lignite	24.8	102.04
Natural gas	**mmBtu/standard cubic**	**Kg. CO_2/mmBtu**
Pipeline (Weighted U.S. Average)	1.028×10^{-3}	53.02
Petroleum Products	**mmBtu/gallon**	**Kg. CO_2/mmBtu**
Distillate Fuel Oil No. 1	0.139	73.25
Distillate Fuel Oil No. 2	0.138	73.96
Distillate Fuel Oil No. 4	0.146	75.04
Residual Fuel Oil No. 5	0.14	72.93
Residual Fuel Oil No. 6	0.15	75.1
Still Gas	0.143	66.72
Kerosene	0.135	75.2
Liquefied petroleum gases (LPG)	0.092	62.98
Propane	0.091	61.46
Propylene	0.091	65.95
Ethane	0.096	62.64
Ethylene	0.1	67.43

Source: IPCC, 2006

Table.6

Energy Conversion Factors

Fuel	BTU/BARRE	BTU/GALLON
CRUDE OIL	5,855,795	139,424
MOTOR GASOLINE	5,250,000	125,000
AVIATION GASO	5,005,224	119,172
JET FUEL	5,434,926	129,403
L.P.G.	4,054,470	96,535
RESIDUAL OIL	6,287,000	149,690

Source: IPCC, 2006

Appendix C

Table.7

Yearly Plant wise Efficiency Ranks (2006-2007)

Plant	2006		2007		2008		2009		2010	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
TPS Jamshoro	19	22	4	17	11	20	2	17	29	12
TPS Guddu (1-4)	25	30	13	24	21	7	21	8	8	5
TPS Muzaffargarh	5	11	22	3	2	31	6	21	**1**	3
NPS Multan	30	7	20	2	22	4	28	5	24	27
SPS Faisalabad	28	10	8	7	17	15	17	16	10	11
TPS Bin Qasim	9	29	10	10	6	25	31	12	27	26
Aes PakGen	18	21	2	32	31	8	9	20	3	1
HUBCO	11	24	18	28	23	17	11	24	30	7
Japan Power	26	25	30	6	10	5	20	4	28	8
KAPCO Kot Adu	12	26	16	29	5	13	24	11	15	17
Kohinoor Energy	20	3	3	**1**	8	6	7	19	32	31
Saba Power	29	6	5	12	26	18	26	**1**	6	10
Tapal Energy	23	13	23	21	3	**1**	10	7	18	19
AES Lal Pir	21	**1**	7	14	19	23	14	23	17	14
GTPS Faisalabad	13	19	31	9	29	11	23	22	12	25
GTPS Korangi	24	4	25	30	14	24	19	15	23	23
GTPS Kotri	10	18	24	5	18	26	**1**	13	21	9
GTPS Site	22	2	29	11	20	2	30	9	25	30
NGPS Multan	27	15	14	26	12	27	16	28	19	29
GTPS Bin Qasim	**1**	16	28	4	28	10	13	25	26	20
GTPS Guddu (5-13)	2	31	6	13	24	9	18	29	7	13
GTPS Jamshoro	3	5	19	19	32	32	32	31	5	15
GTPS Korangi	15	12	26	20	1	12	27	27	14	18
GTPS Muzaffargarh	8	14	21	8	9	19	8	6	4	21
GTPS Quetta	31	8	11	18	27	21	3	2	20	2
Fauji Kabirwala	16	27	17	16	25	30	15	10	9	24
Habibullah	17	9	27	23	13	22	5	14	22	4
KAPCO, Kot Addu	6	23	15	22	7	14	22	3	2	6
Rousch Power	7	17	12	25	30	3	4	18	16	28
TNB Liberty Power	14	28	9	27	16	28	12	26	13	22
Uch Power	4	20	1	15	15	16	25	30	11	16
FBC Lakhra	32	32	32	31	4	29	29	32	31	32

Table.8

Annual Shadow Costs of CO_2 (Rs/kWh)

Plants	2006	2007	2008	2009	2010
TPS Jamshoro	2.542127	2.919022	3.087693	3.377667	3.673132
TPS Guddu (1-4)	2.619229	2.87276	3.075724	3.332743	3.475171
TPS Muzaffargarh	2.657586	2.895928	2.962928	3.230366	3.597221
NPS Multan	3.747107	3.996299	4.50301	4.892444	5.041846
SPS Faisalabad	3.065815	3.503908	3.626725	3.832773	4.307279
TPS Bin Qasim	2.714238	2.897849	3.210188	3.318024	3.535028
Aes PakGen	2.497386	2.732857	2.777887	2.991536	3.192993
HUBCO	2.395512	2.663233	2.711137	2.919128	3.131195
Japan Power	2.267724	2.518106	2.664073	2.042937	3.031518
KAPCO Kot Adu	1.995035	2.204315	2.461392	2.434052	2.842326
Kohinoor Energy	2.015197	2.236734	2.329658	2.420752	2.415246
Saba Power	2.476164	2.740542	2.866798	2.943064	3.412508
Tapal Energy	2.189797	2.42832	2.546298	2.65206	2.915839
AES Lal Pir	2.528406	2.752788	2.876874	2.89841	3.161111
GTPS Faisalabad	0.037639	0.038745	0.041842	0.049491	0.05167
GTPS Korangi	0.053333	0.061418	0.06249	0.062838	0.048185
GTPS Kotri	0.036131	0.039995	0.04314	0.043661	0.047045
GTPS Site	0.052315	0.06051	0.064555	0.075517	0.008031
NGPS Multan	0.050982	0.059489	0.072136	0.05481	0.048185
GTPS Bin Qasim	0.033563	0.039229	0.040813	0.042017	0.046335
GTPS Guddu (5-13)	0.036162	0.039157	0.043811	0.043344	0.051895
GTPS Jamshoro	0.037782	0.042957	0.047088	0.046336	0.054133
GTPS Korangi	0.04449	0.048346	0.047127	0.047502	0.052349
GTPS Muzaffargarh	0.039231	0.044908	0.043713	0.056826	0.08052
GTPS Quetta	0.052689	0.051483	0.056694	0.057795	0.065167
Fauji Kabirwala	0.02495	0.0292	0.024774	0.002518	0.03381
Habibullah	0.024862	0.027633	0.02802	0.029948	0.033133
KAPCO, Kot Addu	0.029463	0.031797	0.036497	0.037838	0.03468
Rousch Power	0.024738	0.027357	0.028086	0.028981	0.032164
TNB Liberty Power	0.024879	0.024854	0.028758	0.029285	0.032681
Uch Power	0.024026	0.025744	0.024934	0.028019	0.030975
FBC Lakhra	5.362802	6.852737	8.892982	7.232659	8.286915

Estimation Results by *STATA 12* Model 1

```
. frontier lpg os lage lcsn  year len

Iteration 0:   log likelihood = -174.75936
Iteration 1:   log likelihood = -172.73276
Iteration 2:   log likelihood = -172.57599
Iteration 3:   log likelihood = -172.57487
Iteration 4:   log likelihood = -172.57487

Stoc. frontier normal/half-normal model          Number of obs   =        160
                                                 Wald chi2(5)    =     704.71
Log likelihood = -172.57487                      Prob > chi2     =     0.0000
```

lpg	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
os	.4593923	.1108354	4.14	0.000	.2421588	.6766258
lage	-.2069439	.0249655	-8.29	0.000	-.2558753	-.1580124
lcsn	.7158556	.072818	9.83	0.000	.5731348	.8585763
years	.1041597	.0444935	2.34	0.019	.0169539	.1913654
len	.2910502	.0496071	5.87	0.000	.1938221	.3882784
_cons	-208.3896	89.38647	-2.33	0.020	-383.5839	-33.19537
/lnsig2v	-1.584973	.2840849	-5.58	0.000	-2.141769	-1.028177
/lnsig2u	-.1281002	.2483882	-0.52	0.606	-.6149321	.3587317
sigma_v	.4527177	.0643051			.3427053	.5980455
sigma_u	.937958	.1164888			.7353078	1.196458
sigma2	1.084719	.1875241			.7171781	1.452259
lambda	2.071838	.1646552			1.74912	2.394557

```
Likelihood-ratio test of sigma_u=0: chibar2(01) = 7.06   Prob>=chibar2 = 0.004
```

Estimation Results by *STATA 12* Model 2

```
. frontier lpg os lage lct lcsn  year len

Iteration 0:   log likelihood = -168.31136
Iteration 1:   log likelihood = -166.10382
Iteration 2:   log likelihood = -165.85393
Iteration 3:   log likelihood = -165.85287
Iteration 4:   log likelihood = -165.85287

Stoc. frontier normal/half-normal model          Number of obs   =        160
                                                 Wald chi2(6)    =     801.53
Log likelihood = -165.85287                      Prob > chi2     =     0.0000
```

lpg	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
os	.5420736	.1086869	4.99	0.000	.3290512	.7550959
lage	-.1790827	.024843	-7.21	0.000	-.227774	-.1303914
lct	-.5951975	.1591236	-3.74	0.000	-.907074	-.2833209
lcsn	.7103435	.0674684	10.53	0.000	.5781078	.8425793
years	.1799465	.0479811	3.75	0.000	.0859053	.2739878
len	.2482222	.0459218	5.41	0.000	.1582171	.3382274
_cons	-356.7942	95.95271	-3.72	0.000	-544.8581	-168.7304
/lnsig2v	-1.719807	.2950222	-5.83	0.000	-2.29804	-1.141574
/lnsig2u	-.1714865	.2424127	-0.71	0.479	-.6466066	.3036336
sigma_v	.4232029	.0624271			.3169472	.5650804
sigma_u	.9178299	.1112468			.7237543	1.163947
sigma2	1.021512	.175758			.677033	1.365992
lambda	2.16877	.1582035			1.858697	2.478844

```
Likelihood-ratio test of sigma_u=0: chibar2(01) = 7.64   Prob>=chibar2 = 0.003
```