

The economic efficiency of thermal power plants economics essay

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Global energy mix today is highly dependent upon fossil fuels, 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 CO₂. 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 then is transformed into electric energy. Electric energy could not be stored for long duration, in order to use it in future. Demand for consumer 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 66.6 percent 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 K and Brett 2011) and (Arthur P. J and David A 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. Human can ensure sustainability in every sphere by adopting the course of efficiency, and it is 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 may 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, and opines 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 opine 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 see (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 the 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 Baortha project 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 installed capacity 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 charge 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 a an even price of 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. However despite of 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 three 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 Pakistan2. To study the Technical Efficiency of thermal power plant in Pakistan3. To study the Environmental efficiency of thermal power plants in Pakistan4. The study aims to estimate Shadow Prices of CO₂ for Thermal Power generationThe 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 ReviewIn 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 factor 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, S 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) and (Bevilacqua and Braglia 2002). Efficiency analyses of power generation plants started in 1970; 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. 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), (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 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 Peypoch 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 Darold 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 technical efficiency. Gas fired plants exhibits greater efficiency than the coal fired plants. See (Fallahi, Ebrahimi and Ghaderi 2011) and (See and Coelli 2011). However some studies found that the difference of fuel type had no impact on technical and economical 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 inclusion for eco-efficient analysis of productivity many efforts have been done to include environmental factor, emissions in case of power generation. The empirical results show that higher the emission 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 Darold 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 an 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 CO₂ Emission Markets, now it is possible to trade CO₂ 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 and 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 (Pakistan 2008). The robust economic growth and rise in per-capita income increased the energy demand 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. 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 (Pakistan 2008).

3. 1 Electricity in Pakistan Pakistan inherited only two power plants with generation capacity of 60 MW, with a per annum growth rate of 7.2 percent the generating capacity of system stood at 19566 MW in 2010. The share of hydroelectric declined from 69 percent in 1960 to 33 percent in 2008 accordingly the proportion of thermal generation increased from 30.9 percent to 66 percent (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. It 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 established, for generation, transmission and distribution of electric power along with flood control and drainage across the country. WAPDA owns more than 58 percent of total installed capacity, and hands round about 88 percent 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 two 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 Of 26: 73. 3. 2Energy and Economic Growth in PakistanBefore 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 (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 slow 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 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 and M 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. 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

Inefficiency Stochastic Frontier Model

The study has employed the stochastic frontier model for the panel data introduced by (Battese and Coelli 1993). Following model is assembled following (Baten, Kamil and Haque 2009); $Y_{it} = \exp(\beta X_{it}) + \eta_{it} - \theta_{it}$ $i = 1, 2, \dots, N$ $t = 1, 2, \dots, T$.

(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. η_{it} and θ_{it} are the random variables which are assumed to be $i. id N(0, \sigma^2)$ and θ_{it} are independent of η_{it} ; θ_{it} are positive random variables associated with technical inefficiency of production, which are assumed to be independently distributed as truncations at zero of the $N(\mu, \sigma^2)$ distribution; where $\mu = z_{it}d$ and variance σ^2 ; z_{it} is a $1 \times p$ vector of

explanatory variables associated with inefficiency of power plant over time, and d is a $1 \times p$ 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 η_{it} are assumed to be a function of the selected explanatory variables, the z_{it} and an unknown vector of coefficients. The technical inefficiency effect η_{it} in stochastic frontier according to (Battese and Coelli 1993) from (1) is specified in equation (2), $\eta_{it} = z_{it}d + \nu_{it}$.. ν_{it} .. ν_{it} ..

(2) Where; the random variable ν_{it} follows truncated normal distribution with mean zero and variance σ^2 , in such a way that the point of truncation is $z_{it}d$, such that $\eta_{it} = \nu_{it}$. These assumptions are consistent with η_{it} being positive truncation of $N(z_{it}d, \sigma^2)$ 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,

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After estimating η_{it} , the technical efficiency of the i th power plant at t th observation is $TE_{it} = \exp(-\eta_{it}) = \exp(-z_{it}d - \nu_{it})$.. ν_{it} ..

(3) 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. $\ln(PG_{it}) = \beta_0 + \beta_1 T + \beta_2 OS + \beta_3 \ln Age_{it} + \beta_4 \ln CSN_{it} + \beta_5 \ln CE_{it} + 1/2 (\beta_{11} T^2 + \beta_{22} OS^2 + \beta_{33} \ln Age_{it}^2 + \beta_{44} \ln CSN_{it}^2 + \beta_{55} \ln CE_{it}^2) + \beta_{12} T * OS + \beta_{13} T * \ln Age_{it}$

respect to time period. The null hypothesis of existence of efficiency is defined as $H_0 : \beta = 0$ where β 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. β is defined as $\beta = (s_{\beta}^2) / ((s_{\beta}^2 + s_{\epsilon}^2))$. In case s_{β}^2 is zero the null hypothesis will be accepted, indicating that β 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). Data on the required variables of thermal plants have been taken from various issues of State of Industry Report yearly published by National Electric Power Regulation Authority. 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. 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 atmospheric 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 CO₂. 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 CO₂ emissions from the energy sector for the period of 1995-2000. There are two main approaches to record CO₂ 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 (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 level with an accuracy level of 95 percent. Estimation of CO₂ emission by fuel analysis approach involves determining carbon content of fuel combusted; the carbon content is then used to quantify the CO₂ 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 than carbon content factors per mass or volume units (IPCC 2006). Moreover the energy value of fuel depends upon the amount of carbon in the fuel rather than 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 = $\sum_{i=1}^n QF_i HC_i CT_i FO_i \cdot 0.001$ (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 CO₂ emission in tons. The Shadow Prices of CO₂ The study attempts to estimate shadow price of CO₂ 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 function 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 (Hailu and Veeman 2000) the study estimated shadow prices CO₂ 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 $T = \{(x, y_g, y_b) : x \text{ produces } (y_g, y_b)\}$. 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 $P(x) = \{(y_g, y_b) : (y_g, y_b) \leq T(x)\}$. Then the input oriented Distance function could be defined as $DF(x, y_g, y_b) = \inf \{\alpha : x/\alpha, y_g/\alpha, y_b/\alpha \in P(x)\}$. 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 $T_E = 1/DF(x, y_g, y_b)$. Table 4. 3 briefly describes the variables used to estimate the shadow prices of CO₂ for thermal power generation in Pakistan.