UNIVERSITI PUTRA MALAYSIA

ENVIRONMENTAL AND COST EFFICIENCY OF STEAM-POWERED ELECTRICITY GENERATION IN IRAN

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IKDPM 2012 3

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DOCTOR OF PHILOSOPHY

UNIVERSITI PUTRA MALAYSIA

2012

Abstract of thesis presented to the senate of Universiti Putra Malaysia in partial fulfillment of the requirements for the degree of Doctor of Philosophy

ENVIRONMENTAL AND COST EFFICIENCY OF STEAM-POWERED ELECTRICITY GENERATION IN IRAN

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December 2012

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During the past two decades, environmental side effects of economic activities have become the central part of public and political discussions. An effective energy policy should encourage the different enterprises, utility companies and individuals to utilize energy efficiently and in more environmental friendly processes, technologies, and materials. Fossil fuels are responsible for the large amount of human-related air pollution in Iran. Due to the fact that more than 45.4% of Iranian electricity is produced by steam plants which are applying fossil fuel, fuel choices play the most important role at national and even international levels. Among the fossil fuels, natural gas plays the most important role in Iran's fuel-fired generating system and is the preferred fuel due to its cleaner combustion characteristics compared to other fuels. Since few researches had examined the environmental and economic tradeoffs among the different fuels, this study estimates the contribution of gas, fuel oil and gas oil inputs and compare it with an

alternative substitute (LNG) to illustrate the best available environmental and economical choice for the largest electricity generation sector in Iran.

To minimize SO_2 emissions and costs, the study applies a Data Envelopment Analysis followed by Charnes, Cooper and Rhodes (CCR) and then DEA-MBP followed by Coelli et al., 2005 that incorporates the material balance principle (DEA-MBP) in the first stage of the analysis. Findings are evident that by switching to natural gas, the substantial increase (nearly 80%) in environmental efficiency and cost efficiency (nearly 30%) would result while the technical efficiency would demonstrate a nearly 7% decrease. Therefore, results highlight the positive impact of fuel switching on Cost and Environmental efficiency scores respectively. By considering the investment pay-back, the study indicated that small-sized power companies are not considered economical to switch to mini LNG.

In the second stage of our analysis, the Ordinary Least Square (OLS) estimator were employed to extract the missing factors in the first stage by regressing the technical, cost and environmental efficiency scores derived from the DEA on the explanatory variables (age, size, fuel type and year of observation) which could influence the efficiency levels of the steam plants in Iran which may not have been considered in the first stage analysis. The study provides a comprehensive efficiency analysis of specific applications of steam power plants in Iran to serve the applied strategy to the component stakeholders for doing policy implication. The results clearly demonstrate that by switching to natural gas and instructing medium and large size plants instead of small ones, the environmental efficiency would increase dramatically and the cost efficiency also would indicate an increase while the technical efficiency demonstrates little decrease. Therefore, being aware of the tradeoffs for individual and also public policy makers seems necessary. Furthermore, it would be mostly valuable to indicate what changes would be necessary to increase the efficiency of the most inefficient plants to the level of their efficient peers. Thus, considering new incentive systems seems reasonable to encourage the best fuel resources and other factors which simultaneously fulfill the desire for cost and environmental efficiency especially sulfur reduction.

Abstrak tesis yang dikemukakan Kepada Senat Universiti Putra Malaysia sebagi memenuhi keperluan untuk Ijazah Doctor Falsafah

KECEKAPAN ALAM SEKITAR DAN KOS PENJANAAN BERKUASA WAP ELEKTRIK DI IRAN

Oleh

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Dalam tempoh dua dekad yang lalu, kesan sampingan alam sekitar aktiviti ekonomi telah menjadi perbincangan awam dan politik yang utama. Satu dasar tenaga yang berkesan harus menggalakkan perusahaan yang berbeza, syarikat-syarikat utiliti dan individu untuk menggunakan tenaga dengan lebih cekap dan lebih mesra alam sekitar dalam pemprosesan, teknologi, dan bahan-bahan. Bahan api fosil adalah bertanggungjawab bagi jumlah yang besar pencemaran udara yang berkaitan manusia di Iran. Disebabkan hakikat bahawa lebih daripada 45.4% elektrik Iran dihasilkan oleh loji janakuasa stim yang menggunakan bahan api fosil, pilihan bahan api memainkan peranan yang paling penting di peringkat kebangsaan dan juga peringkat antarabangsa. Antara bahan-bahan api fosil, gas asli memainkan peranan yang paling penting dalam sistem penjanaan di Iran dan menjadi bahan api pilihan kerana ciri-ciri pembakaran lebih bersih berbanding dengan

bahan api lain. Oleh kerana beberapa kajian telah pun meneliti ‘tradeoffs’ alam sekitar dan ekonomi antara bahan api yang berbeza, kajian ini menganggarkan sumbangan gas, minyak bahan api dan input minyak, gas dan bandingkan ia dengan alternatif pengganti (LNG) untuk menggambarkan pilihan terbaik bagi alam sekitar dan ekonomi untuk sektor penjanaan elektrik terbesar di Iran.

Untuk meminimumkan pengeluaran dan kos SO_2, kajian ini menggunakan ‘Data Envelopment Analysis’ (DEA) diikuti oleh Cooper, Charnes dan Rhodes (CCR) dan kemudiannya menggunakan DEA-MBP diikuti pula oleh Coelli et al, 2005 yang menggabungkan prinsip imbangan bahan (DEA-MBP) pada peringkat pertama analisis. Penemuan ini adalah jelas bahawa dengan beralih kepada gas asli, kecekapan alam sekitar meningkat besar (hampir 80%) dan kecekapan kos juga meningkat (hampir 30%) manakala kecekapan teknikal menunjukkan penurunan hampir 7%. Oleh itu, keputusan menyerlahkan kesan positif skor kecekapan Kos dan Alam Sekitar untuk penukaran bahan api. Dengan mengambil kira jangka bayar balik pelaburan, kajian menunjukkan bahawa syarikat-syarikat janakuasa yang bersaiz kecil tidak dianggap ekonomik untuk beralih ke mini LNG.

Dalam peringkat kedua analisis kami, penganggar kuasa dua terkecil biasa (OLS) digunakan untuk mengekstrak faktor yang hilang dalam peringkat pertama dengan melakukan regresi skor kecekapan teknikal, kos dan alam sekitar yang terbit dari DEA itu pada pembolehubah penerangan (umur, saiz, jenis bahan api dan tahun pemerhatian) yang boleh mempengaruhi tahap kecekapan loji stim di Iran yang tidak mungkin telah dipertimbangkan dalam analisis peringkat pertama. Kajian ini menyediakan analisis kecekapan menyeluruh aplikasi tertentu loji kuasa stim di Iran untuk menggunakan strategi kepada komponen berkepentingan untuk membuat implikasi dasar. Keputusan jelas menunjukkan bahawa dengan beralih kepada gas asli dan mengarahkan loji saiz sederhana dan besar dan bukannya yang kecil, kecekapan alam sekitar akan meningkat secara mendadak dan kecekapan kos juga akan meningkat manakala kecekapan teknikal menunjukkan penurunan yang sedikit. Oleh itu, pembuat dasar individu dan juga awam seolah-olah perlu menyedari 'tradeoffs' ini. Tambahan pula, ia akan menjadi sangat berharga untuk menunjukkan apa perubahan yang perlu untuk meningkatkan kecekapan loji yang paling tidak cekap ke tahap rakan-rakan mereka yang cekap. Oleh itu, suatu sistem insentif baru adalah munasabah untuk menggalakkan sumber-sumber bahan api yang terbaik dan faktor-faktor lain yang secara serentak memenuhi keinginan untuk pengurangan kos dan kecekapan alam sekitar terutamanya sulfur.

DEDICATION

To my life little GODDESS

My strong father

and

My patient mother

ACKNOWLEDGMENTS

First and foremost, I would like to extend my deepest praise to Allah who has given me the patience, strength, determination and courage to complete this project within the allotted time frame.

It is my pleasure to thank and convey my highest appreciation to my committee chairman, Professor Dr. Khalid B Abdul Rahim for his tremendous support throughout this study and his willingness to share his knowledge and patience in completing this thesis.

I also would like to thank my supervisory committee members, Assc.Prof.Dr. Alias B Radam and Dr. Mohd Rusli Bin Yacob for guide me to understand methodology. I would dedicate my special thanks to the last by not least to my Iranian committee member, Dr. Shahin Mohammadnejad, for giving me the good direction to pursue my study and his helpful suggestions, views and comments at various stages of the study.

My deepest gratitude goes to my parents for their infinite inspiration, encouragement and accompanying me during the most difficult task/time along this study.

I certify that an Examination Committee has set on *3 December 2012* to conduct the final examination of Foroogh Shadman Lahiji on her Doctor of Philosophy thesis entitle " ENVIRONMENTAL AND COST EFFICIENCY OF ELECTRICITY GENERATION IN IRAN" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulation 1981. The committee recommends that the candidate be awarded the relevant degree.

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

FOROOGH SHADMAN LAHIJI

Date: 3 December 2013

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CHAPTER ONE

INTRODUCTION

1.1 General Background

Energy is essential for life. The important part of economic systems within life itself is energy. To meet the largest part of their energy demands, most industrialized countries rely on oil and its derivatives and natural gas, which are depletable and non- recyclable energy sources. Energy is deemed to be a key player in wealth generation and also a significant component in economic development. To make sure that energy fulfills the needs for economic growth and sustainable development more attention should be paid to energy efficiency for both end-use and supply, and especially in recent years, environmental protection should be considered. In any country, an effective energy policy should encourage the different enterprises, utilities, and individuals to make use of energy efficiency and more environmental friendly processes, technologies, and materials.

Harmonizing environmental protection with economic growth in order to ensure fulfillment of goods and services to provide future generation and a better environmental quality through the improvement of eco-efficient productive processes is the key component of sustainable development. Furthermore, the incorporation of environmental protection issues into management strategies has fundamental importance to drive producers and consumers towards the choice of technologies and products with less environmental harmful impact.

Iran, with an area that is roughly 1,648,000 Km^2, is located in the heart of the Middle East and also is among the countries with the largest oil and gas reserves in the world. Even though Iran's economy depends heavily on oil export revenues (around 80% of total export earnings, 40%-50% of the government budget, and 10%-20% of GDP) its production has dropped by more than a third from a peak of over 6 Million Boe/D in 2000. Petroleum is the main fuel for meeting the total energy requirements in Iran. Domestic demand for oil derivatives grew rapidly during the period 1971-2000, however its share of total final energy consumption has decreased from 75.91% in 1971 to 56.87% in 2000. Iran has turned to natural gas as a substitute for the domestic consumption of petroleum products. Natural gas plays a most important role in Iran's fuel-fired generating system and is the preferred fuel due to its cleaner combustion characteristics compared to other fuels. Natural gas has negligible acid gases like sulfur, which limits sulfur compound emissions, insignificant amount of ash that limits particulate matter emissions, and NO_x emission rates which are lower than from other fuel types in general. The electric power industry is attempting to extend monitoring activities in order to maintain national and international regulations in Iran.

1.2 Importance of Electricity Generation in Iran

The power generation sector for all countries' economic development has an important implication. In Iran, power sector plays a critical role in energy production, consumption and also environmental pollution emissions. However, the issue of fossil fuels policies in Iran is rather complex and depends on many factors, especially economic, politic and technical parameters. These parameters included the cost of the fuels used in power plants, geographical location, availability of the fuel, environmental concerns and also policies of the energy sector.

Iran` is a member of OPEC (Organization of Petroleum Exporting Countries) which is responsible for about 78% of the world oil reserves and produces about 45% of the world oil production. The country is one of the main exporters of energy such as crude oil and natural gas with approximately 11% of world oil reserves (136 billion barrels). According to Oil and Gas Journal, Iran also has the second largest reserves of natural gas in the world only after Russia with approximately 19.7% of the world proven natural gas reserves which are about 28,080 billion cubic meter(U.S. Department of Energy, 2011).

In 2007, Iran was the world's fourth largest producer and third largest consumer of natural gas. Due to the natural gas resources abundance, Iran aims to increase its gas burning capacity to fulfill its energy requirements within the country for public use, industrial use and even export to neighboring countries. Thus, generating electricity from natural gas in Iran is the government priority, economically cheaper and environmentally cleaner characteristics.

In 2000, the natural gas consumption had increased from 12 MBoe in 1971 to 220.5 MBoe growing at nearly 11.7% annually and contributed 32.76% of the total energy consumption (in 1971, this value was 13.31%). The oil is the source of more than 80% of the government's foreign currency income and therefore the reduction of oil derivatives consumption has been pursued by policy makers to enable the country to export petroleum products. The reduction in oil consumption will be achieved by applying natural gas via the expansion of gas network pipelines. Iran has the potential to be a large natural gas exporter due to its enormous reserves. Iran produced about 2.2 trillion cubic feet of natural gas in 2001 in which around 10% was flared, and approximately 30% was re-injected to enhance oil recovery efforts. Hence, the flared and re-injected amount of gas indicated the abundance of the resource in the country. In 2000, electricity accounted for 8.39% of the total energy consumption. The largest domestic gas consumer in Iran accounting for about 37.6% of the total was electricity sector (U.S. Department of Energy, 2003).

In 2009, Iran generated a projected 201.6 billion kilowatt-hours (Bkwh) and consumed 161.5 Bkwh. From this 97% of electricity generation (172 Bkwh) was generated by conventional thermal electric power, and the rest were generated by hydroelectric source, and a marginal amount of renewable (solar and wind) power (U.S. DEPARTMENT OF ENERGY, 2009). Increasing the installed capacity in Iran seeking to achieve by roughly 10 percent annually, keeping in line with its projected 7-9 percent annual demand growth (U.S. DEPARTMENT OF ENERGY, 2009). Meeting higher demand is focused mainly through expanding combined-cycle and hydroelectric power. Due to severe drought during late 2007 and early 2008 which affected Iran's hydroelectric production adversely, water reservoirs became empty during the summer peak demand season which resulted in a drop of nearly 70 percent in hydroelectricity power generation. Thus, Iran's ability to fulfill its domestic power obligations was brought into question, let alone its export obligations. Hence, changing the steam powered plant fuel into mostly natural gas which is economically cheaper and environmentally cleaner is growing fast (U.S. DEPARTMENT OF ENERGY, 2009).

The total electricity generated in 2008, 190.2 billion kWh (93.3 percent) was generated by power plants associated with the Ministry of Energy and 13.6 billion kWh (6.7 percent) by other institutions, mostly in the private sector. In 2008, electricity generation was 203.8 billion kWh or roughly one percent of world's total production which compared with the previous year was up by 5.9 percent. The steam generated power plants had the largest share of electricity (91.1 billion kWh) while the lowest share of generation (0.2 billion kWh) accounted for diesel power plants. Iran also exported 5.5 TWh of electricity annually to seven surrounding countries namely, Afghanistan, Pakistan, Iraq, Turkey, Armenia, Azerbaijan and Turkmenistan.

By the end of 2010, Iran had a total installed electricity generation capacity of 61,000 MW (increasing from 90 MW in 1948 & 7024 MW in 1978) and planned to add annually more than 5,000 MW of generation capacity to the grid and double the total power generation capacity in Iran to 122,000 MW in the next 10 years (by 2021). Iran is expected to produce 17.08% of MENA (Middle East and North Africa) power generation by 2014. In 2009 Iran’s dominant fuel was gas, accounting for an estimated 56.8% of primary energy demand (PED), followed by oil at 40.8% and hydro with a 1.4% share of PED (PressTV., 2012). The average power plants efficiency was 38 percent in 2010 and should attain 45 percent within five years and 50 percent under Vision 2025 (Zawya, 2012).

The annual growth of electricity production in Iran was 12.3% and the annual nominal capacity growth was 10.35% which is equivalent to an annual growth of 5058 MWh of electricity generation that need to be produced by new power generation capacity of 1239MW annually.

1.3 Problem Statement

The power industry, which has been constructed and operated under a supply- follows-demand philosophy, always have been able to attain its obligation at the lowest possible cost by providing adequate and secure supplies of electricity. It means that the objective of the power generation plant to obtain a certain reliability level is to find the most economical generation expansion scheme to fulfill the predicted demand increase during a certain period of time. However, this has resulted in an onerous operating strategy requiring high plant margins and large scale environmental impact from the local to the global level as it is one of the major energy consuming sectors and a large contributor of environmental pollution emissions.

In Iran like other parts of the world, the power sector plays an important role for economic development. It also has a critical implication on energy production and consumption and environmental pollution emissions. Fossil fuels generated about 94% of electricity operated by thermal plants in Iran and about 6% were generated by renewable sources during the past decade.

Iran is situated in the Middle East and due to the large size of the country, great variation can be seen in weather conditions across the country especially the four seasons: spring, summer, autumn and winter. The northwest of Iran is typically cold with heavy snowfall and sub-freezing temperatures in winter. The weather in the central part - The Lout Desert, stretching for hundreds of miles - is hottest during summer and coldest during winter in Iran whilst in the southern regions of Iran, the weather is often fairly mild during these periods. Based on these geographical conditions, Iranians rely largely on natural gas for space and water heating combined with the cold climate, especially in winter and autumn. It means that Iran has the highest gas consumption per capita in Iran during winters and autumn. Due to this geographical condition, the government recommends to power plants and industries to provide appropriate substitute fuels when the government cannot provide them natural gas.

In Iran, steam power plants with 15,598 MW nominal capacity is equivalent to 29.5% of the total nominal capacity producing 45.4% of total electricity generation. Natural gas is a primary-fuel which mainly contributing to the steam electricity generation in Iran. Fuel oil and gas oil are the emergency backup fuels which are used for steam power plants especially in the winter and autumn when the residential usage of natural gas is maximum and therefore the pressure in the national gas pipeline would drop and based on government recommendation, power plants and industries have to switch their fuel type. The substitute fuels considered for steam plants are fuel oil and diesel which are both oil derivatives.

Thus, steam powered plants substitute fuel is mostly fuel oil and also diesel which is discharge large amount of air emissions specially SO_2, SO_3 and Suspended Particulate Matter (SPM) in comparison with natural gas. Compared to natural gas, these alternative fuels contain 1637 and 447 times more sulfur compound for fuel oil and gas oil respectively compared to natural gas. Sulfur Dioxide which is the main consideration in this study has been recognized as a primary contributor to acid rains and impede breathing problems especially during winters and autumns where pollutants are trapped under cold weather and cannot disperse easily, Then harmful side effects of these emissions will be larger even in global level.

One of the main pollutants which is produced in the electricity sector, according to data provided by IIASA (International Institute for Applied Systems Analysis, 2006), is Sulfur dioxide. SO_2 emissions in the electricity sector was generally responsible for 75% of the pollution at the national level INE-SEMARNAT(Instituto Nacional de Ecologı´a-Secretarı´a de Medio Ambiente y Recursos Naturales, 2006) in 2002. Important negative effects on human health have been linked to this pollutant (Lo´ pez et al., 2005; Lu¨ bkert-Alcamo & Krzyzanowski, 1995; Spix & Wichmann, 1996) as well as to acidification of soils, forests, rivers and lakes (Bini & Bresolin, 1998; Schindler, 1998; Sienkiewics *et al.*, 2006). Corresponding to EPA, breathing impeded by high concentrations of sulfur dioxide (SO2) and existing cardiovascular or respiratory diseases may worsen. Asthmatics, individuals with bronchitis or emphysema, children and the elderly are particularly vulnerable to these health effects. Air quality is also affected by sulfur compound. Finally, the abatement of SO_2 is necessary because the SO_2 is known as primary contributor of acid rain which causes acidification of lakes and streams and can damage trees, crops, historic buildings and statues.

In conclusion, sulfur dioxide is one of the main pollutants in the fossil burned power sector which its reduction seems to be taken more importance. Switching to less environmentally polluted fuels, as well as more advanced technologies to control mazut and diesel emissions seems necessary. In addition, the alternative fuels are more expensive than natural gas because they both are oil derivatives that using them reduces export potential or in some cases when they are imported they impose more cost to the government. Then, it is necessary for power plants to find an effective way to balance the economic and environmental objectives.

1.4 Objectives of the Study

Large proportion of human-related air pollution produced by fossil-fuel originated from electricity generation sectors in Iran. Therefore, key determinants of the industry's impact on national and even global levels are fuel choices. The main objective of this study is to examine the most economical and environmental tradeoffs in power generation plan using different types of fuels that incorporate the material balance principle in the data envelopment analysis (DEA) procedure to estimate the allocation between gas, diesel and fuel oil inputs that minimize SO_2 and costs. The primary contribution of the study is that it demonstrates a methodology that can be used by Decision Making Units (DMUs) on how to balance the costs and benefits of SO_2 abatement by electricity utility producers.

One of the most practical mechanisms to reduce SO_2 emissions from the electricity sector is by switching from high- to less- emission production utilities. Alternative fuel proposed in this study to substitute the most polluted fuels like gas oil (diesel) or fuel oil (mazut) for steam power plants during winters or peak shaving time is the liquid natural gas (LNG). This is considered feasible to mitigate SO_2 emission in this study. Our study includes scenario analysis among the different types of fuel used by these plants to reach at efficient plan of power generation system based on the economic and environmental tradeoffs.

The specific objectives are:

1. To analyze technical, environmental and cost (in)efficiency of steam-powered electricity generation units utilizing Data Envelopment procedure incorporating the Material Balance Principle measurement in Iran.
2. To estimate and compare the cost and environmental efficiency for the plants when switching to liquefied natural gas (LNG) instead of fuel oil and gas oil.
3. To examine the degree in which the most important internal (power plant size, age) and external (fuel type, year of observation) factors influence technical, cost and environmental efficiency levels of steam power plants in Iran which help to provide a recommendation for public policy, especially in electricity generation in Iran.

1.5 Significance of the Study

As a rule, the goal of environmental policy is to meet the best environmental results like minimum emission at minimum cost to the system. This is done by taking into account the policy parameters of using different types of fuels which also differ in their respective prices and environmental impact.

In 2006, Iran with over 45 GW installed nominal capacity ranked the first among the middle east countries and 17th in the world (Khosroshahi KA *et al.*, 2009). In 2008, electricity generation in the country attained 214 TWh with the growth of about 5.0% in comparison to previous year. Thus, like other developing countries, the majority of energy sources used in Iranian power plants are fossil fuels. Thermal power plants are the main contributor of electricity generation in Iran which is operated by fossil fuels and produce huge amounts of air pollutants (IEA., 2008).

In 2011, Mazandarani et al. reviewed the economic growth in Iran from 1967 to 2008 (42 years), where per capita electricity consumption has increased by about 4000%, equivalent to an average annual growth rate of 9.5% which was much higher than the average population growth (2.5%). During this time, the average annual growth rate of emissions was 8.6% for CO_2, 8.5% for SO_2, 10.3% for NO_2 and 8.6% for CO. The change in the amount and type of emission from fuels used fluctuated in some years.

In order to meet high electricity demand and due to the huge fossil fuel resources in the country, the electricity generation from fossil fuel is much higher than renewable resources. The type of fuel which is used for power plants in Iran depends on many factors, especially economic, political and technical parameters such as the cost of the fuels, geographical location of the power plants, availability of the fuel, environmental concerns and medium and long-term policies of the energy sector.

The present study planned to apply DEA-MBP methodology in the first stage to estimate technical, cost and environmental efficiency scores. The DEA method of measuring efficiency is fundamentally based on the work by Farrell (1957) which was further extended by Charnes, et al. (1978) and Banker *et al*. (1984) to measure the efficiency of each DMU to obtain the maximum ratio of weighted outputs to weighted inputs. Fare et al.(1996) were the first to consider the environmental variables into firm-level efficiency analysis methods which supposed that pollution reduction would be costly.

Based on new environmental efficiency measures defined by Coelli (2005), environmental efficiency (*EE*) of a firm is equal to the ratio of minimum pollutant over observed pollution (Coelli, et al., 2005; Coelli T. J., et al., 2007). The model gives the ability to more clearly demonstrate that pollution reduction in some cases can be cost reducing at a point that has tended to be neglected in a number of past studies. The method also shows that past methods which introduced pollution variables into production technology may contain definite shortcomings when the materials balance condition is realized.

The environmental efficiency is measured (proxied) by levels of SO_2 and economic efficiency is measured by fuel price. However, SO_2 could not be a comprehensive measure of environmental performance, but it is the most important pollutant for the electricity generation and industries specially when heavy fuels were applied (Ilinitch *et al.*, 1999; Lanen, 1999). Therefore, being informed about cost efficiency and environmental efficiency and also the relationship would be the significant concern to management, policy makers and government officials.

In Iran, executive bylaws (approved in 2000) for paragraph (c) of article 104 and article 134 referred to the law of third plan of Economic, Social and Cultural development of the Islamic republic of Iran that must be fulfilled by industries and power plants in order to meet SO_2 allowable emission levels within critical zones. It is undeniable, of course, that prosecution of environmental offenders is only one potential tool in the expanding array of compliance mechanisms available to regulatory agency officials. However, offence and penalty provisions will continue to be part of environment protection legislation but it appears that such provisions seems to be inappropriate tool to protect environment due to public plants contradict to pay the penalty to government.

The small amount of fine and penalty and also lack of cost-benefit tradeoffs have not prompted utility companies to respond to the pollution emissions reduction and by its very complexity have not encouraged officials to enforce the regulation. Therefore, due to natural gas resource abundance and its inexpensive price, it is possible to avoid from the gaps between inappropriate environmental and ineffective cost of production and also sustainable policy intervention which would require recognizing the significant potential tradeoffs among the different types of fuels used by the plants. Thus, the study aims to estimate the benefits of switching to cleaner production instead of enacting and enforcing new laws. Therefore, the gap between cost efficiency and also environmental efficiency could be narrowed. This study aims to find out the cost and environmental efficient combination of fuel to control SO_2 emission options using alternative fuel for steam power plants during different seasons. There is no similar study undertaken for this sector in Iran.

Finally, in 2009, to address the economic and environmental tradeoffs among the different types of fuels used by the plants, Welsch *et al*., applied a DEA procedure that incorporated the materials balance principle to estimate the allocations of coal, gas and oil inputs that minimize carbon emissions and costs. Thus, awareness of the tradeoffs between environmental and cost efficiency and technical efficiency in steam electricity plants is necessary for selecting the best fuel substitute.

Efficiency argument implies that there is a role for the government to play in order to control air pollution. Therefore, governments ought to contrive mechanisms for reducing SO_2 emissions when researchers provide better information about cost and environmental efficiency as well as technical efficiency to enhance efficiency outcomes.

1.6 Contribution of the Study

A combined major in economics and environmental studies is having a strong interest in economic aspect of environmental issues. Thus, understanding the causes of and designing policy solutions to environmental problems which also make economically sense is a government priority.

Efficient use of energy is essential for sustainable development. Due to the global impact of environmental issues, the study concerns primarily with emissions of the main electricity sector in Iran which is steam power generation focusing on SO_2 emission with an in depth assessment of the environmental and cost efficiency and allocative efficiency to give a clear information to government officials, public policy maker and also individual plants of the cost and SO_2 trade-offs. Thus, our findings could provide valuable information for policy makers and decision making units regarding how to allocate the cost and benefits of sulfur abatement by electricity producers as well. Decision making units' (DMUs) performance can also be improved by identifying the best and worst practices associated with high and low environmental and cost efficiency employing emission discharge taxes imposed by the government through environmental legislation in Iran respectively.

In essence, the frontier based efficiency techniques is a useful tool for both decision making units and policy makers alike. The method allows researcher to benchmark the cost and environmental efficiency of firms in the industry and provide recommendations on areas of improvement. Based on the findings, policy implications and recommendations can be outlined and proposed.

The efficiency assessment of electricity generating sector in this study is undertaken by applying the material balance principle into non-parametric DEA methodology. The DEA methodology distinguishes three different types of efficiency measures namely technical, environmental and cost efficiencies. The DEA approach also provides an overall efficiency level and subsequently could be used as a benchmarking tool. The MBP method is tied more closely to economic methodology that is true for most other DEA approaches which deal with undesirable outputs. Therefore, its value will increase when physical productivity, economic prices, and pollution costs are the primary concerns. The DEA-MBP approach helps to identify both economic and environmental trade-offs in energy production.

To give an insight to the policy making units in Iran in micro and macro levels (individual plants and public policy makers) for technical and environmental efficiency and the best allocation of them, this study applies DEA-MBP methodology based on Coelli et al. (Coelli *et al.*, 2005, 2007) and further applied by Welsch and Barnum (2009) for the United States steam plants. It is then followed by McDonald (2009), where the Ordinary Least Square (OLS) is applied in the second stage to investigate the degree in which various factors influence the technical, cost and environmental efficiency levels. McDonald (2009) investigated the application of OLS in the second stage which is followed by Banker (1993), (Banker, R. D. & Natarajan, 2008) and (Hoff, 2007) arguing that DEA efficiency scores are a particular kind of fractional or proportional data and suggested that OLS is an unbiased, consistent estimator, and, can be validly undertaken if heteroskedasticity is allowed for hypothesis tests.

This study applies seasonal data to highlight the fuel selection in the latest three years (2007 to 2009) which lead to removing fuel subsidies in Iran. The study focuses on the technical, cost and environmental efficiency analysis of the steam power plants which is the main contributing sector in the country to highlight the importance of allocative efficiency. This study takes advantages of secondary data extracted from TAVANIR

(Power Generation and Transmission Management Organization), which is owned, operated and administrated by the Ministry of Energy (MOE), unless otherwise specified.

1.7 Organization of the Study

The thesis is organized in five chapters. After the introduction chapter, the remainder of this study is organized as follows: Chapter two is divided into three parts where, part one describes the introduction on the general background of electricity sector and geographical location of Iran. Part two is theoretical framework and the discussion will cover the basic concepts of Material Balance Principle (MBP) and technical and allocative cost and environmental efficiency, and measurement using non-parametric approaches namely the Data Envelopment Analysis. Part three will have a review on empirical studies on Data Envelopment Analysis which were applied in electricity generation sector including pollution variable, then studies that covered the Materials Balance Principle (MBP) and finally recent researches that incorporated the materials balance principle into data envelopment analysis which analyzed both economic and pollutant inputs and outputs.

Chapter three presents the methodology to be used in the study including methods which are employed to examine the technical, cost and environmental efficiency. In addition, selection of independent variables used in the regression models will be discussed in this chapter. Data collection and their sources and variable used in the study are also presented.

In Chapter four the analysis of the empirical results of the study will be presented. In particular, the results will be classified according to existing conditions and proposed conditions using suggested alternatives in this study and examining the economic and environmental tradeoffs among different types of fuels taking environmental pollution impact into account in steam based electricity generation sectors in Iran to consider whether there is the gap between efficient cost or efficient environmental production.

Chapter five summarizes the study and key findings. The managerial and policy implications arising from the results are discussed. The limitations to the study will also be highlighted. The chapter concludes with some policy recommendations and directions for future research.

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