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Greenhouse gas emission measurement and economic analysis of Iran natural gas fired power plants ☆

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HIGHLIGHTS

- CO_2 and NO_x emissions of Iran natural gas fired power plants have been studied.
- CO_2 and NO_x emission factors are compared with EPA, EU and World Bank standards.
- Costs and benefit as economic functions are obtained according to capacity factor.
- Maximum economic profit is obtained for gas turbine and steam power plants.
- Investment in CO_2 reduction is recommended instead of investment in NO_x reduction.

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ABSTRACT

This study attempts to examine the natural gas fired power plants in Iran. The required data from natural gas fired power plants were gathered during 2008. The characteristics of thirty two gas turbine power plants and twenty steam power plants have been measured. Their emission factor values were then compared with the standards of Energy Protection Agency, Euro Union and World Bank. Emission factors of gas turbine and steam power plants show that gas turbine power plants have a better performance than steam power plants. For economic analysis, fuel consumption and environmental damages caused by the emitted pollutants are considered as cost functions; and electricity sales revenue are taken as benefit functions. All of these functions have been obtained according to the capacity factor. Total revenue functions show that gas turbine and steam power plants are economically efficient at 98.15% and 90.89% of capacity factor, respectively; this indicates that long operating years of power plants leads to reduction of optimum capacity factor. The stated method could be implemented to assess the economic status of a country's power plants where as efficient capacity factor close to one means that power plant works in much better condition.

1. Introduction

Nowadays, climate changes and people's health problems are known as the most serious environmental issues and one of the main sources of climate change is fossil fuel power plants. Reasonable estimation of greenhouse gas emissions is essential for developing an appropriate policy to better address the global warming and people's health problem.

Fossil fuel power plants are great consumers of fossil fuel resources and are among greatest industrial emission producers. Emissions from power plants pose a potentially large risk to human health and the environment (Lopez et al., 2005). Therefore, any attempt for optimizing power plant operation and the renovation of its facilities, including economic and environmental attitudes, will gain huge benefits in the long time. Further, socio-economic and environmental factors should be evaluated together in the selection of area for creating new thermal power plants (Say, 2006). Therefore, it could be concluded that power plant emissions such as CO_2 could be reduced with optimizing power plant operation and renovation of its facilities. Amount of CO_2 not only damages the environment and causes financial losses, but also damages ozone layer. The energy sector accounts for

☆In this study "full load" means the nominal capacity that a specific power plant produces but "load" means the measured value of the working load in the experiment day (during 2008).

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approximately 90% of the CO_2 emissions and 75% of the total greenhouse gas emissions in developed nations (Intergovernmental Panel on Climate Change IPCC, 2006). Capturing CO_2 from exhaust gas at thermal power generation systems (PGSs) is considered as an effective means of dramatically reducing CO_2 emissions into the atmosphere. Technologies of capturing CO_2 include pre-combustion, post combustion and oxy-combustion methods (Davison, 2007; Kanniche et al., 2010). The impact of capturing CO_2 from fossil fuel power plants on the emissions of NO_x and SO_x is favorable. Although, due to the reduced efficiency of power plants equipped with capturing technologies, the large-scale implementation of capturing carbon increases the emission levels of NO_x from the power sector, but some NO_x and SO_x can be removed during the CO_2 capture (Tzimas et al., 2007). Using the CO_2 capture repowering system, the unit cost of power is about 18.0% cheaper and the annual profit 6.68 times larger than that of the reference system. However, the depreciation year of the proposed system is estimated to be longer than that of the reference system (Pak et al., 2010).

The most efficient load of a newly established power plant is its nameplate capacity. As time elapses, efficiency and the load up on which the power plant has the highest efficiency reduces; therefore it proves most efficient if power plants work on the efficient load (and not the nameplate capacity factor). This study aims to find the ratio of efficient load to the nominal capacity. If power plants work on the efficient load which is addressed here, it will yield the most economic benefit. Prior to this study, authors have investigated CO_2, CO, SO_2 and NO_x emission factors of Iran's fossil fuel fired power plants and have concluded that these power plants do not work on an efficient load (Alavije et al., 2010).

This research evaluates the amount of Iran's natural gas fired power plant emissions during 2008. The study is based on thirty two gas turbine and twenty steam power plants for estimation of CO_2 and NO_x emission factors. The nameplate capacity of the power plants ranges from 60 MW to 315 MW for steam power plants and 15–165 MW for gas turbine power plants. The total nominal and produced capacities of Iran's governmental power plants are about 46 GW and 42 GW, respectively. The overall nominal capacity of the gas turbine and steam power plants are 11,798.7 MW and 14,935 MW, respectively. The overall electricity produced in gas turbine and steam power plants are 9807 MW and 14,565.6 MW, respectively. Therefore, it can be concluded that total capacity factor of gas turbine and steam power plants are 83.1% and 97.5%, respectively. Natural gas consumption is 16,000–72,000 m^3/h for steam power plants and 4900–45,418 m^3/h for gas turbine power plants (Environment Protection Department of Niroo Research Institute (NRI), 2008). Further, the developed emission factors are compared with those for other group works. An economic analysis is preformed which prefers the optimum power plant operation based on parameters such as fuel consumption cost, generating electricity revenue, emission cost, power plant load etc. In addition, the EF[1] values of natural gas fired power plants are compared with the standards of EPA[2], EU[3] and World Bank.

2. Background

2.1. Emission

The total power generation increased from 16,921 MW to 31,295 MW from 1993 to 2003 and it is expected to reach 71,675 MW by 2013 (Iran's Ministry of Energy, 2007). This indicates that the production capacity is doubled every decade, consequently increasing gas emission of power plants in 2003 for CO_2, SO_2, NO_x and PM_{10} production was 24.5%, 22%, 11.2% and 4.5%, respectively. Based on the energy balance sheet reported in 2003 and according to World Bank and Iran environment protection organization the social costs of power plant pollution are about 59.5, 371.4 and 195 million dollars due to NO_x, SO_2 and CO_2 production, respectively. Social costs are calculated by multiplying the amount of pollutant by the environmental costs per unit of weight. These costs were adopted from Iran's Ministry of Energy's information bank (Iran's Ministry of Energy, 2008). Totally, the cost estimation is an annual amount of about 625.9 million dollars (Environment Protection Department of Niroo Research Institute (NRI), 2008). It has been shown that if the power plant composition remains the same, the CO_2 emission in 2025 will be 252 Mt and SO_2, NO_x and CO emissions will reach 72%, 119% and 126%, respectively (Mazandarani et al., 2011).

2.2. Energy resources

Lack of energy resources is one of the main universal issues in the field of energy policy and is true for Iran. Efficient utilization of the limited resources is one of the low cost procedures to tackle this problem. Working of power plants on the efficient load leads to the better economic exploitation of energy resources. The energy sector of Iran is dominated by oil and gas. Iran is one of OPEC[4]'s largest oil producers and holds 8.6% (12.3 billion tons) of the world's oil reserves as well as 17% (26.6 trillion m^3) of its gas reserves. Oil production in 2000 amounted to 186.6 million tons that is 3.8 million barrels per day (Motlagh et al., 2004). Four countries located in the Middle East own about half of world's natural gas resources (Iran, Qatar, Saudi Arabia and United Arab Emirates). It is remarkable that developed countries have the most amount of gas production in the world. On the other hand, statistics show that gas consumption for heat generation and electricity have been growing to higher rates during recent years (since 1995). These increases are more considerable in Middle East and non-OECD[5] Asia Pacific and illustrate that world's tendency for using natural gas as well as the natural gas consumption for power plant fuel is growing (Department of Resource, Energy and Tourism, Australian Government, 2010). Gas consumption is increasing because of its low emission factor (A´rmannsson et al., 2005).

Growth in use of natural gas is more sensible in Iran due to her great resources of natural gas. Iran has been expanding its urban natural gas distribution since 1980. The growth rate has accelerated in recent years (International Energy Agency, 2010).

Comparison between the energy intensities of Iran and a few developed and developing countries makes clear that Iran uses energy wastefully and identifies energy efficiency as an area where some real progress needs to be made. Meanwhile, USA and China, despite having more production industries, use 17% and 26% less than Iran (Motlagh et al., 2004).

3. Method

In order to calculate the emission factors, the CO_2 and NO_x concentration and the flow rate of flue gas were assessed by Testo 350 XL analyzer. The instrument was placed at the accessible location of the flue gas duct. Further measurements were taken

[1] Emission Factor.
[2] Energy Protection Agency.
[3] Euro Union.
[4] Organization of Petroleum Exporting Countries.
[5] Organization for Economic Co-operation and Development.

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