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Experimental determination and analysis of CO_2, SO_2 and NO_x emission factors in Iran's thermal power plants

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ABSTRACT

Emission factors of CO_2, SO_2 and NO_x emitted from Iran's thermal power plants are fully covered in this paper. To start with, emission factors of flue gases were calculated for fifty thermal power plants with the total installed capacity of 34,863 MW over the period 2007–2008 with regard to the power plants' operation characteristics including generation capacity, fuel type and amount and the corresponding alterations, stack specifications, analysis of flue gases and physical details of combustion gases in terms of g kWh^{-1}. This factor was calculated as 620, 2.57 and 2.31 g kWh^{-1} for CO_2, SO_2 and NO_x respectively. Regarding these results, total emissions of CO_2, SO_2 and NO_x were found to be 125.34, 0.552 and 0.465 Tg in turn. To achieve an accurate comparison, these values were compared with their alternatives in North American countries. According to this comparison, emission factor of flue gases emitted from Iran's thermal power plants will experience an intensive decline if renewable, hydroelectric and nuclear types of energy are more used, power plants' efficiency is increased and continuous emission monitoring systems and power plant pollution reduction systems are utilized.

1. Introduction

Linkages between energy use and environmental quality have always been apparent, from the deforestation caused by fuel wood use even in early societies to the high levels of local air and water pollution that have commonly accompanied the early phases of industrialization. In recent decades, advances in scientific understanding and in monitoring and measurement capabilities have brought increased awareness of the more subtle environmental and human-health effects associated with energy production, conversion, and use. Fossil-fuel combustion is now known to be responsible for substantial emissions of air pollutants (including sulfur, nitrogen oxides, hydrocarbons, and soot) that play a major role in the formation of fine particulate matter, ground-level ozone, and acid rain [1]. In addition, acceptance potential of the environment regarding pollutants reception is a crucial principle in constant development of industrial plans of a country so that the feasibility of such plans in a region is determined by measuring the pollutants' emission in that area. The importance of the understudy subject has inspired comprehensive studies and researches in different countries [2–5].

Iran stands among the few top rich countries possessing primary energy resources in the world. Enjoying considerable energy resources particularly in gas and oil fields, as well as retaining a geopolitical and geo-economic position in the region, Iran has obtained a valuable and unique condition. Thus, the power industry of Iran has been based upon three fossil fuels including gas, gas oil and heavy oil, which produce over 90% of the electric power of this country [6].

Natural gas, heavy oil and gas oil are the most significant fossil energy sources used for power generation in Iran [6].

Quantitatively, gas has the highest consumption for electricity generation (87,530 TJ in 2008), while heavy oil is less consumed (19,592 TJ in 2008), and gas oil has the least consumption (8738 TJ in 2008)[6]. Combustion of fossil fuels by professional power industry results in the emission of SO_2, NO_x, CO and CO_2 in atmosphere. Among all power plants in Iran, steam units have the highest share of electricity generation. Share of steam units in total electricity generation was equal to 45.4% in 2008 (97.1 TWh) [6]. Existence of old steam units with low efficiency, high consumption of heavy oil in cold seasons of the year and absence of conventional systems reducing air pollutants' emission and their incomplete combustion leads to high production of air pollutants. In 2008, Iran generated 214 TWh electricity of which, 170 TWh was consumed. Of this amount, 209 TWh was generated by conventional thermal electric power plants, and about 5 TWh was produced by

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hydroelectric units, with a marginal amount of renewable (wind) power provided [6].

In 2008, shares of gas-turbine, combined-cycle, hydro electric, wind turbine and diesel engine power plants in total electricity generation were 25.6, 26.6, 2.2, 0.1 and 0.1% respectively [6]. Iran is projected to generate up to 713 TWh of electric energy in 2025 [7].

As of 2007, EIA (Energy Information Administration, Official Energy Statistics from the U.S. Government) shows no nuclear electric power generation. Iran seeks to increase its installed capacity by roughly 10 percent annually, keeping in line with its projected 7–9 percent annual demand growth. Iran has been focused on meeting higher demand mainly through expanding combined-cycle and hydroelectric power plants. However, severe drought during late 2007 and early 2008 adversely affected Iran's hydroelectric production, leaving water reservoirs emptied during the summer peak demand season, resulting in a drop of nearly 70 percent in hydroelectricity power generation. This has brought into question Iran's ability to fulfill its domestic power obligations. Consequently, as of late 2007 some 85 water dams were under construction [8].

Iran's Ministry of Energy estimates that to meet the projected demand growth, total capacity must reach 136.32 GW by 2025. Iran continues to develop its nuclear program to generate electricity. Its first nuclear power plant with 1000 MW capacity is to be built at Bushehr with Russian assistance and operations are to begin in 2010. Russia is also providing fuel under an agreement singed in early 2005. Iran plans to generate 6000 MW of electricity through nuclear technology by 2025 [8].

Like other industries, according to growing trend of demand and electricity supply in two last decades, gaseous pollutants emitted from thermal power plants must be estimated. Pollutants mass in time unit can be determined by measuring the concentration of gases exiting the stacks and flow rate of flue gas. According to clean air regulations, consideration of industrial pollutants distribution amount is a path toward the recognition and measurement of air quality. To this end, emission factor is computed and evaluated to provide the administrators with an operational tool to control air quality. Emission factor and estimation of its value is considered as a key tool for the development of emission control strategies. This factor is usually expressed as the resulting pollutants intensity divided by the product or the initial material (the unit of weight, volume, distant, generated energy or pollutant distribution time) [9]. For instance, in a coal-consuming industry, floating particles emission in terms of kilogram for each mega gram of coal represents the emission factor of floating particles produced by that industry. Emission factor can be calculated by several different methods including material balance, modeling and using flue gas analyzer, which is considered to be the best method.

In general, emission estimation equation is as follows [9]:

$$E = A \times EF \times (1 - ER/100) \quad (1)$$

E = pollutant emission amount
A = activity rate (production amount of industrial unit, for example the tonnage of produced cement or the generated electricity in terms of kWh)
EF = emission factor
ER = total emission reduction percentage, which is equal to zero if pollution reduction systems are not used.

In power plants, emission factor is expressed based on the intensity of produced pollutants or flue gases in terms of generated electric energy or consumed thermal energy with regard to energy consumption and generation growth over the past two decades and outstanding share of thermal power plants in energy generation, measurement of gaseous pollutants' emission from thermal power plants sounds vital. Emission factor of CO_2, SO_2 and NO_x emitted from each type of Iran's fossil-fuel power plants (steam, gas-turbine and combined-cycle) is experimentally presented in this paper. This way, power plant pollutant emission factors were measured and calculated by using analysis and measurement of flue gases for the first time in Iran. This achievement can be a precise source for the calculations related to the future development plans of Iran's power plants [10].

2. Fuel types used in Iran's thermal power plants

Natural gas, heavy oil and gas oil are the most significant energy resources used for electricity generation in Iran. The mean calorific value of fuel types consumed in Iran's thermal power plants is represented in Table 1. Heavy oil used in Iran's steam power plants is featured with the following mean quality parameters: net calorific value – above 42 MJ kg^{-1} – and high sulfur contents – about 3% (Table 2). Gas oil combusted in gas-turbine and combined-cycle power plants is featured with mean net calorific value – 44.8 MJ kg^{-1} – and sulfur contents ranging from 0.82 to 0.98 percent (Table 2). Natural gas used in Iran's thermal power plants is featured with high calorific value above 55 MJ kg^{-1} and low sulfur content (Table 3).

Natural gas consumption indicator for electricity generation in Iran was equal to 10.15 MJ kWh^{-1} in 1999. In 2003, it amounted to 9.51 MJ kWh^{-1}, while in 2008 it reached 9.79 MJ kWh^{-1}. The efficiency of gross electric power generation came to 35.5% in 1999. In 2003, it totaled 37.8% and it eventually rose to 36.8 in 2008 [6].

In case of heavy oil, the consumption indicator in electric power generation added up to 10.23 MJ kWh^{-1} in 1999, 10.21 MJ kWh^{-1} in 2003 and 10.5 MJ kWh^{-1} in 2008. The efficiency of gross electric power generation numbered 35.2% in 1999, 35.25% in 2003 and 34.3% in 2008 [6].

For gas oil, the consumption indicator in electric power generation added up to 13.1, 12.3 and 11.53 MJ kWh^{-1} in 1999, 2003 and 2008 respectively. The efficiency of gross electric power generation was calculated as 26.3% in 1999, 29.3% in 2003 and 31.2% in 2008 [6].

Iran's strategic aim is to support the development of renewable energy recourses, nuclear energy and fossil-fuel energy sources in 2025 [7].

In Iran's energy perspective report (2006), it was assumed that the largest potential to be used in 2025 comes to the seven energy sources based on Table 4.

Expanding the amount of electricity generation using renewable resources and technologies (biomass, wind, solar, geothermal, fuel cell and ocean energy) is widely considered desirable for several reasons:

- Environmental and public health benefits
- Energy security benefits
- Development and economic benefits

Table 5 represents the consumption of basic primary energy carries in Iran's thermal power plants over the period 1999–2008. Natural gas consumption increased from 44,471 TJ in 1999 to 87,530 in 2008. Heavy oil usage had a progressive drop from

Table 1
Average net calorific values of fuel used in Iran's thermal power plants [6].

Fuel type	Average net calorific value (MJ kg^{-1})
Natural gas	55.60
Heavy oil	42.40
Gas oil	44.80