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SHORT RESEARCH AND DISCUSSION ARTICLE

Effect of nuclear power on CO_2 emission from power plant sector in Iran

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Abstract
Introduction It is predicted that demand for electricity in Islamic Republic of Iran will continue to increase dramatically in the future due to the rapid pace of economic development leading to construction of new power plants. At the present time, most of electricity is generated by burning fossil fuels which result in emission of great deal of pollutants and greenhouse gases (GHG) such as SO_2, NO_x, and CO_2. The power industry is the largest contributor to these emissions. Due to minimal emission of GHG by renewable and nuclear power plants, they are most suitable replacements for the fossil-fueled power plants. However, the nuclear power plants are more suitable than renewable power plants in providing baseload electricity. The Bushehr Nuclear Power Plant, the only nuclear power plant of Iran, is expected to start operation in 2010. This paper attempts to interpret the role of Bushehr nuclear power plant (BNPP) in CO_2 emission trend of power plant sector in Iran.
Materials and methods In order to calculate CO_2 emissions from power plants, National CO_2 coefficients have been used. The National CO_2 emission coefficients are according to different fuels (natural gas, fuels gas, fuel oil).
Results and Discussion By operating Bushehr Nuclear Power Plant in 2010, nominal capacity of electricity generation in Iran will increase by about 1,000 MW, which increases the electricity generation by almost 7,000 MWh/year (it is calculated according to availability factor and nominal capacity of BNPP).
Conclusions Bushehr Nuclear Power Plant will decrease the CO_2 emission in Iran power sector, by about 3% in 2010.

Keywords CO_2 Emission · Electricity generation · Nuclear power plant · Iran

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1 Introduction

Financial development and the rise of living standards led people to cope with the bad side effects caused by factors that sustained this development for many years. Evaluation of power plants is not simple as several criteria are involved to cover every aspect of modern society. Multicriteria analysis and externalities assessment can be applied to evaluate electricity generation systems on the living standard (Chatzimouratidis and Pilavachi 2007; Athanasios et al. 2008).

Today, electricity demand is growing rapidly leading to construction of new power plants. Resources are depleting, and sustainable solutions are exploring. Global warming is no more ignored, and international agreements and protocols are signed in order to prevent proliferation of greenhouse gases (GHGs) (Wehner 2006; Zwaan and Gerlagh 2006).

Fossil fuels supply more than 85% of all commercial energy in the world and are the source of more than 68% of the commercial electricity. Also in the generation of electricity, fossil fuels may stay in pole position for some time (Verbruggen 2008).

Very explicitly, now, energy policy is addressing environmental issues, and energy conservation has come to be regarded as an important element of environmental policy. According to the current situation, concern for environmental preservation has increased the demand for more efficient management and environmentally sound and sustainable development of nuclear energy (Lee and Koh 2002).

The international endeavor about climate change was culminated with the entering into force of the Kyoto Protocol to the UNFCCC in February 2005, which commits developed countries and economies in transition (known as Annex B countries) to reduce their overall emissions of six GHGs by an average of 5.2% below 1990 levels between the years 2008 and 2012 (i.e., the first commitment period) (Weisser et al. 2008).

One disagreement at the UN level is whether or not nuclear power should play a role in a post-2012 climate change agreement. Albeit the fact that nuclear power virtually emits no GHG at the level of the power plant and ranks among the lowest electricity-generating option with regard to lifecycle GHG releases (Weisser 2007).

Indeed, recent international studies point to a role of nuclear power in combating climate change alongside other energy supply and demand side mitigation options (IEA 2006; EPRI 2007; IPCC 2007).

It is necessary to mention that nuclear energy has been excluded from Kyoto Protocol's Clean Development Mechanism and Joint Implementation as an eligible technology (Weisser et al. 2008).

All energy systems emit GHGs and contribute to anthropogenic climate change (Weisser 2007).The electricity generation contributes a large share of CO_2 emissions. So, electricity generation industry is one of the most important sectors for an effective greenhouse gas control strategy (Weisser 2007; Hammons 2006).

Several alternative technologies are available to reduce this industry's emission such as hydropower and wind power. A substantial supply side shift away from fossil fuel resources relies on diverse technologies, due to limitation of each individual alternative. For example, nuclear power is hindered by licensing and waste storage issue, as well as uncertain public acceptance. Massive expansion of hydroelectric, wind, and solar power is limited by a combination of liabilities including resource constraints, declining site characteristics, intermittency, and grid stability (Meier et al. 2005).

Environmental benign, nuclear power generation is a carbon-free process. In this process, other gases (mainly inert gases) emitted to the air are not as massive and diverse as emissions from fossil fuel combustion. Release of radioactive isotopes is the most significant source of contamination; massive releases happen in case of accidents (Shrader-Frechette 1991).

Advocates of nuclear power have recently framed it as an important part of any solution aimed at fighting climate change and reducing GHG emissions. The Nuclear Energy Institute (2007) tells us: "It is important to build emission-free sources of energy like nuclear" and that nuclear power is a "carbon-free electricity source" (1998). Patrick Moore, co-founder of Greenpeace, has publicly stated that: "Nuclear energy is the only non-greenhouse gas emitting energy source that can effectively replace fossil fuels and satisfy global demand" (Benjamin 2008).

Resources of fossil fuels are plentiful, but finite, which eventually will limit the use of these fuels. The Iran with considerable amount of oil and gas resources is one of the exporters of primary energy. However, during the past three decades, due to the ongoing process of social and economical developments, the present strategy of utilizing energy resources in the country is being halted by two unavoidable situations. On one hand, considering the improving living standards and supporting plans towards boosting gross domestic production (GDP), the increasing trend of energy demands of all domestic sectors have to be fulfilled and on the other hand, the country's economy is largely dependent on foreign currencies earned out of oil exports. Under such circumstances, the present trend of utilizing such depletable fuels is bound to be aimfully altered with a view of obtaining a long and sustainable energy planning for the country. Moreover, the real value of fossil fuels is much more precious than simply burning them for their heat and due to limited lie of oil reserves, the share of the nest generation is also to be considered so that they may have better options to unitize these badly treated treasures. On the other hand, environmental issues are becoming important worldwide (Gorashi 2007).

A large amount of GHG emissions belongs to Energy Sector[1] of Iran, especially fossil-fueled power plants (FFPP). In other words, fossil fuels combustion in power plants is responsible for most of the anthropogenic greenhouse gas emission in Iran. The fraction of GHG emission in FFPP has been reached up to 24% in 2007[2] (Ministry of Energy (MOE) 2009).

1.1 Electricity generation in Iran

According to the population census in 2006, Iran has a population of over 70.5 million (Statistical Center Information 2007).

Figure 1 shows the annual growth of population and GDP during a period of 40 years (1968–2007) in Iran (MOE 2001, 2008, 2009).

[1] Energy Sector in Iran means energy consumers sector which include of household and commercial sector, transport sector, industry sector, refinery sector, and agriculture sector.

[2] At the time of preparing this paper, the last official statistical report of energy sector and greenhouse gas emissions of it in Iran belongs to 2007, so the data used in this paper is a 40-year period, since 1968 to 2007.

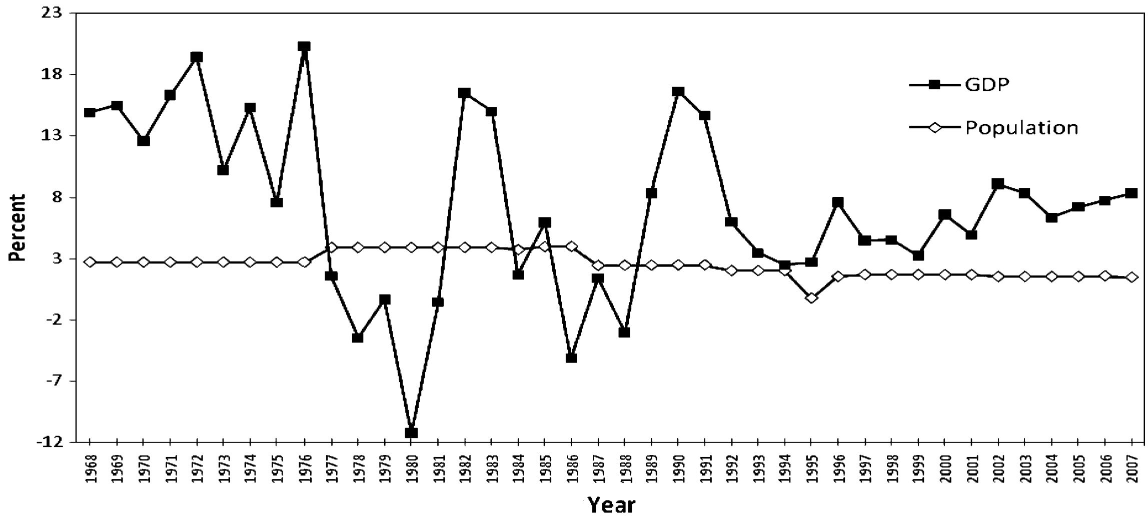

Fig. 1 Annual growth of population and GDP during the 40-year period in Iran (1968–2007) (MOE 2001, 2008, 2009)

In year 2007, the primary energy production and final energy consumption were equal to 2427.8 and 975.2 million barrels of crude oil equivalent, respectively. Annual growth of total primary energy and total final energy consumption during a period of 40 years in Iran (1968–2007) is shown in Fig. 2 (MOE 2001, 2009).

Steam power plants, combined cycle power plants, gas power plants, hydropower plants, and diesel power plants have the most shares in Iran's electricity generation, respectively. Renewable power plants (including wind and solar) have a small role in electricity generation (MOE 2007; IEA 2009).

Electricity demand fluctuates in the short term in response to business cycles, weather conditions, and prices. Decisions to add capacity and the choice of fuel type depend on the electricity demand growth, the need to replace inefficient plants, the costs, and the operating efficiencies of different options and fuel prices (EIA 2009).

Formulated plans for increasing the capacity of the Iran's electricity generation system are based on the following policies:

- Orientation towards gas and combined cycle power plants taking into account their high efficiency and technological developments in manufacturing them
- Completion of hydropower plants which are currently in progress and increasing system reserve and stability in order to prevent outages, as well as providing the required facilities for power plants to operate in safe conditions and in accordance with generation standards
- Increasing the capacity of steam power plants during the coming years is not among the MOE's principal Policies
- In order to meet the transmission demand of the newly established generation capacities, transmission substations and line establishment plans are being strenuously pursued (Karbassi et al. 2007)

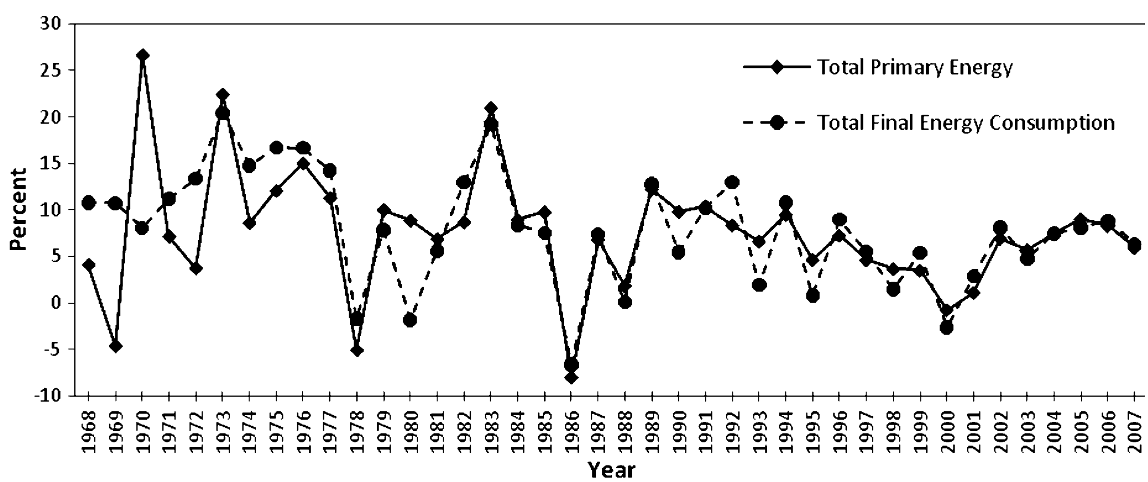

Fig. 2 Annual growth of total primary energy and total final energy consumption during the 40-year period in Iran (1968–2007) (MOE 2001, 2009)

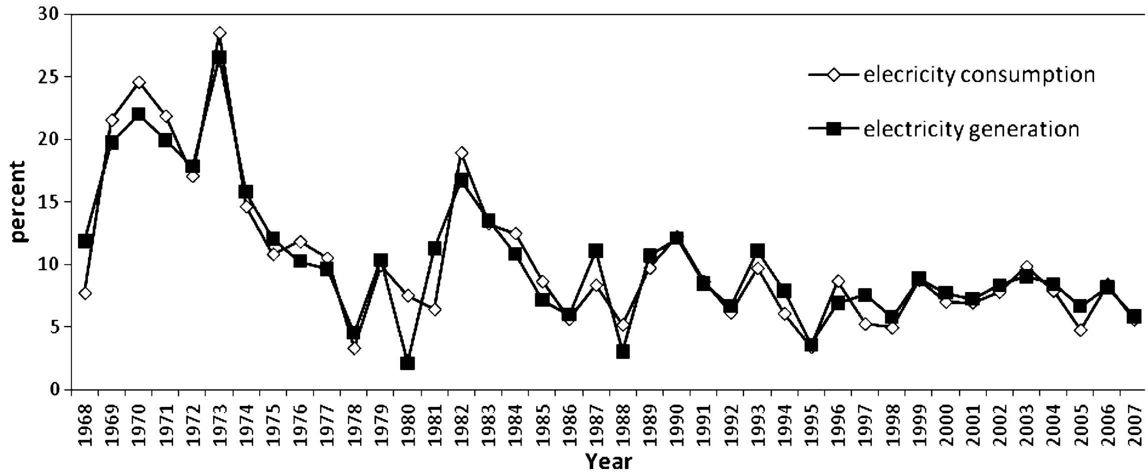

Fig. 3 Annual growth of electricity generation and consumption during the last 40 years in Iran (1968–2007) (MOE 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009)

According to Iran's current policies on diversification of electricity supply, in future, the electricity generation with fossil fuels will be substituted by the renewable and nuclear energies. Also, distributed generation systems are considered in planning of electricity generation in Iran. According to the time table of different operating power plants, the capacity of MOE power plants should increase from 43.9 GW in the year of 2007 to 88.9 GW in the year of 2015 (an increase of about 103%) (MOE 2009).

Figure 3 shows the annual growth percent of electricity generation and consumption during the past 40 years in Iran (1968–2007) (MOE 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009).

Figure 4 shows the increasing trend of the gross electricity generation and consumption during the 40-year period of (1967–2007) in Iran. The electricity generation in 2007 is about 100 times higher than that in 1967. Also, electricity consumption has the same trend in the studied period (MOE 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009).

2 Methodology

In order to calculate CO_2 emissions from power plants, national CO_2 coefficients have been used. The national CO_2 emission coefficients are according to different fuels (natural gas, fuels gas, fuel oil).

2.1 CO_2 emissions and power plants

Thermal (or fossil fuel) power plants are one of the major pollution sources of CO_2 emissions due to carbon fuel combustion, which results in a buildup of the greenhouse gases in the atmosphere, leading to the global warming (Prisyazhniuk 2006, 2008).

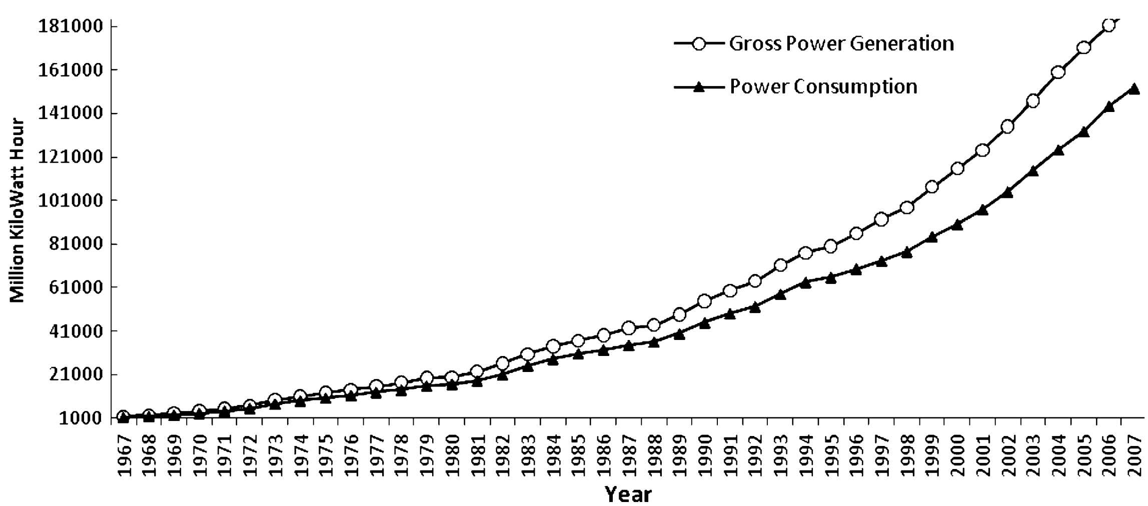

Fig. 4 Trend of gross electricity generation and power consumption during a period of 40 years in Iran (1967–2007) (GWh). (MOE 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009)

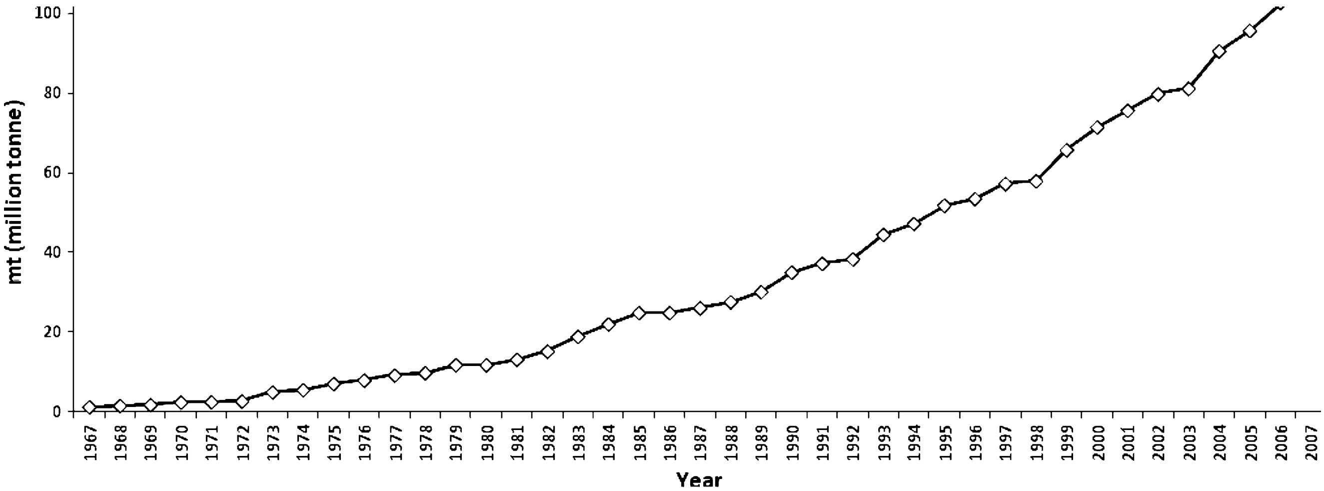

Fig. 5 Trend of CO_2 emission in thermal power plant sector of Iran during the last 40 years (1967–2007) (MOE 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009)

According to increasing electricity generation during the studied period (1967–2007) in Iran, CO_2 emission has been increased too. As shown in Fig. 5, CO_2 emission from FFPP of Iran in 2007 is almost 80 times greater than the one related to 1967 (MOE 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2009).

3 Nuclear energy in Iran

One of the main missions of Atomic Energy Organizartion of Iran (AEOI) is to apply nuclear energy to generate electricity under supervision of International Atomic Energy Agancy safeguards. In relation to nuclear power plant construction and development, the most important activities of AEOI could be categorized to the following main fields:

- Completion of Bushehr Nuclear Power Plant
- Design and construction of research reactor based on domestic potentials
- Site Selection for new nuclear power plants in order to increase the nuclear electricity generation to 20 GW (MOE 2008).

In order to supply the required nuclear fuel for future nuclear power plants, Iran has been involved in the following activities:

- Uranium exploration and mining
- Uranium ore concentrate production (Yellowcake)
- Uranium Processing for different uranium products (UCF[3])
- Uranium enrichment
- Production of pipes, zirconium bars, and other new alloys (ZPP[4])
- Production of nuclear fuel assembly (FMP[5])
- Production of heavy water (D_2O) in industrial scale (Secretariate of Scientific Cooperation Council 2008).

3.1 Introduction of Bushehr Nuclear power plant

Bushehr NPP unit 1 with *VVER1000/V446 pressurized water reactor* consists of four coolant loops, reactor coolant pump, and horizontal steam generator on each loop. The unit 1 has the standard emergency core cooling system including high-pressure pumps, low-pressure pumps, and hydro-accumulators. Primary pressure maintenance system consists of pressurizer, surge line, spray line, and pulse safety facility. Reactor pressure vessel has four inlet and four outlet nozzles (0.834 m diameter); the outlet nozzles are located at a higher elevation than the inlet nozzles. Reactor coolant system (RCS) transports heat from the reactor core to the steam generators that provide steam to the turbine generators through the main steam lines. Four primary coolant loops have common flow path through the reactor vessel. Each RCS loop includes a horizontal steam generator, a main circulation pump (RCP). The primary coolant flows from the reactor outlet nozzle to the steam generators and then is pumped by RCP to the reactor inlet nozzle. The pressurizer, which maintains overall system pressure (16 MPa), compensates the changes in the primary coolant volume. The pressurizer is connected to the cold and hot legs of the primary loop piping by a spray pipeline and an injection pipeline in one of the loops. The steam generators are horizontal units, with submerged tube bundles. Each unit includes a cylindrical horizontal shell, two vertical nozzles, U-shaped tubes of 0.013 m internal diameter and 0.0015 m thickness. The primary coolant flows through the tube side and the feed water is delivered to the shell side (Nematollahi and Zare 2008).

[3] Uranium Conversion Facility
[4] Zirconium Production Plant
[5] Fuel Manufacturing Plant

Table 1 Some characteristics of Bushehr Nuclear Power Plant

Parameter	Dimension	BNPP value
Thermal reactor power	GW	3.1
Electric power	MW	1000
Fuel type	–	Uranium dioxide
Weight of fuel	tonne	80
Number of fuel complex	–	163
Height of fuel complex	m	4.57
Pressure at the reactor outlet	MPa	15.7±0.3
Pressurizer level	M	7.80
Coolant temperature at the reactor inlet	°C	291
Coolant temperature at the reactor outlet	°C	321
Secondary pressure	MPa	6.27±0.1
Main feed-water temperature	°C	220
Emergency feed-water temperature	°C	40

Source: (Nematollahi and Zare 2008; Bushehr Nuclear Power Plant 2009)

Some characteristics of Bushehr Nuclear power plant (especially reactor) has been described in Table 1 (Nematollahi and Zare 2008; Bushehr Nuclear Power Plant 2009).

4 Results and discussion

4.1 Effect of Bushehr Nuclear power plant on CO_2 emission

In order to study the effect of Bushehr Nuclear Power Plant on CO_2 emission from electricity generation sector in Iran, two scenarios could be assumed as follow:

1. Operating of BNPP in coming years (1,000 MW Nuclear Power Plant)
2. Substitution a fossil fuel power plant instead of Bushehr Nuclear Power Plant (1,000 MW thermal power plant)

4.1.1 Scenario1: trend of CO_2 emission in Iran power plant sector with operating of BNPP

By operating BNPP in 2010, nominal capacity of electricity generation in Iran will increase about 1,000 MW, which increases the electricity generation almost 7,000 MWh/year (it is calculated according to availability factor and nominal capacity of BNPP).

On the other hand, according to statistics, 2.6 GW power plants is operated in 2010, which consists of 12.4% gas power plants, 83.7% combined cycle power plants, and 3.9% hydro power plants. (MOE 2009)

Also, according to the same statistics, all nominal capacity of thermal plants in 2015 will be 45 GW, in which the role of steam power plants, gas power plants, combined cycle power plants, hydro power plants, and nuclear power plant (Bushehr Nuclear Power Plant) are, respectively, 1.4%, 6.5%, 79.7%, 10.2%, and 2.2% (MOE 2009).

Therefore, the electricity generation plan in Iran is to develop combined cycle power plants in future.

4.1.2 Scenario 2: substitution a fossil fuel power plant instead of BNPP (1,000 MW thermal power plant)

In this scenario, CO_2 emission will be determined if a fossil fuel power plant is assumed to be instead of BNPP. Considering the plan of Iran for developing combined cycle power plants and reducing other kinds of fossil-fueled power plants, it is assumed that a combined cycle power plant with the same electricity generation as BNPP is operated.CO_2 emission trend for two scenarios is shown in Fig. 6.

As shown in Fig. 6, BNPP will decrease the CO_2 emission in Iran power sector, about 3% in 2010.However, in 2015, its role is only 1.7% in decreasing CO_2 emission in power sector. Maybe the value of decreasing CO_2 emission looks small, but it is worth mentioning that a reduction of 3% in 2010 is equivalent to a reduction of 3.7 million tons in CO_2 emission. In addition, according to the plan for developing the nuclear power plants in Iran up to about

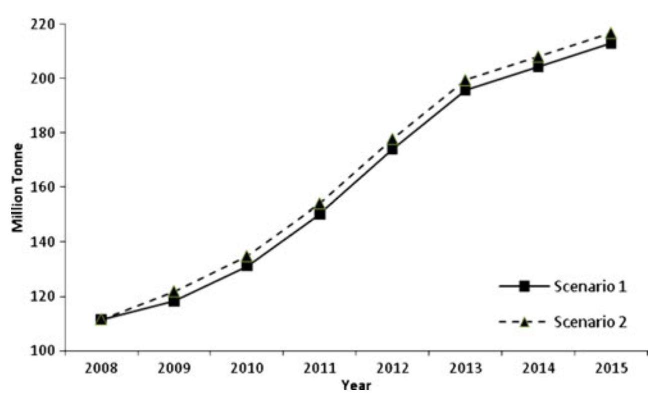

Fig. 6 CO_2 emission trend for *Scenario 1* and *Scenario 2*

20 GW, CO_2 emission reduction value will be more considerable in future years (approximately, 74 million tons per year).

5 Conclusion

- Electricity generation in Iran in year 2007 is about 100 times more than electricity generation in 1967.
- Fossil fuels combustion in power plants is responsible for most of the anthropogenic GHG emission in Iran. The fraction of GHG emission in Iran's FFPP was 24% in 2007.
- CO_2 emission from Iran FFPPin 2007 was almost 80 times greater than the one related to 1967.
- BNPP does not have a considerable effect on the Trend of CO_2 emission of Power Plant Sector in Iran.
- It is predictable that operating of 20 GW Nuclear Power Plant in Iran will cause a considerable decrease in CO_2 emission from Power Plant Sector.

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