ELECTRICITY GENERATION AND CONSUMPTION IN IRAN AND THE ROLE OF NUCLEAR POWER FOR SUSTAINABLE ENERGY

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FACULTY OF ENGINEERING

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Abstract

Over the years, the consumption of all types of energy, such as electricity, have increased rapidly in Iran. The economic growth of the country depends on electricity, and, therefore, the trend of electricity consumption is likely to keep growing in the future to sustain this growth. In view of this need, the government plans to build many new power plants and decided to redevelop its nuclear program to meet the rising electricity demand and decrease the consumption of fossil fuels. In this study, the effect of this policy on four major aspects of energy sustainability, including environmental pollution, electricity demand, energy security and electricity price have been verified.

A clear view of 43 years of the evolutionary trend of the country's power sector, has been shown by gathering data, including the capacity installed, electricity generated and amount of fossil fuel used from the years 1967 to 2009. In addition, the future power plant composition for Iran is investigated, and the fuel consumption and emissions predicted until 2025. In recent decades, thermal power plants generated about 94% of electricity and about 6% was generated by renewable sources such as hydropower. If the dominance of new power plants is by thermal type, the CO_2 and other air pollutant emissions will increase. The results show that increasing the share of renewable sources and the construction of 20,000 MW nuclear reactors will reduce 26% of hazardous CO_2 emissions into the environment; nevertheless, there are some other effective policies and technologies that can be implemented to control the emissions.

In respect of answering the country's growth rate for energy demand, which is very high, neither nuclear nor fossil fuels can cope with the current growth. Therefore, the only solution is rationalizing the energy demand and controlling energy wastage by encouraging energy efficiency.

In the field of energy security, although Iran has huge oil and gas reserves, it faces many threats. The major threats are the high growth rates of energy consumption, economic dependency on crude oil exports, wastage of energy, lack of attention to common fossil fuel resources and political conflict. Therefore, the energy policy must be reformed to address these problems rather than investing in nuclear facilities.

To investigate the relative cost of electricity generated in each alternative generator, the simple levelized electricity cost was selected as a method. The results show that in the country's current circumstances, the electricity cost in fossil fuel power plants will be cheaper than nuclear.

In conclusion, although nuclear energy, including its fuel cycle is Iran's assured right, constructing more nuclear power plants will not solve the energy sustainability problems. In fact, it may be the catalyst for deterioration since it will divert capital and other finite resources from top priority and economic projects such as energy efficiency, high-technology development and energy resources management.

Abstrak

Sejak berdekad yang lalu, peningkatan pesat bagi semua jenis tenaga termasuklah tenaga elektrik telah berlaku di Iran. Tenaga elektrik juga telah membantu kepada pertumbuhan ekonomi di negara ini. Oleh itu, penggunaan elektrik haruslah berkekalan demi menjamin pertumbuhan ini. Memandangkan keperluan tenaga elektrik yang tinggi di negara ini, kerajaan telah mengambil keputusan untuk membina lebih banyak loji janakuasa baru dan merancang untuk membangunkan semula program nuklearnya demi memenuhi peningkatan permintaan tenaga elektrik dan seterusnya mengurangkan penggunaan bahan api fosil. Dalam kajian ini, empat aspek utama kemampanan tenaga telah dikenalpasti termasuklah pencemaran alam sekitar, permintaan tenaga elektrik, keselamatan tenaga dan seterusnya harga elektrik.

Evolusi sektor kuasa di negara ini selama 43 tahun dari tahun 1967 hingga 2009 telah ditunjukan melalui pengumpulan data, termasuklah kapasiti elektrik yang dipasang dan bahan api fosil yg digunakan. Di samping itu, komposisi loji kuasa pada masa hadapan di Iran juga dikaji, dan ramalan penggunaan bahan api dan pencemarannya sehingga tahun 2025 telah dibuat. Dalam sedekad yang lalu loji kuasa termal menghasilkan kira-kira 94% daripada tenaga elektrik dan 6% selebihnya dijana oleh sumber yang boleh diperbaharui seperti kuasa-hidro. Jika pembinaan loji janakuasa yang baru juga didominasikan daripada jenis *termal*, maka pelepasan CO_2 dan lain-lain pencemar udara akan meningkat. Keputusan kajian menunjukkan bahawa dengan meningkatkan bahagian sumber-sumber yang boleh diperbaharui dan pembinaan reaketor nuklir berkuasa 20,000 MW akan mengurangkan perlepasan CO_2 yang berbahaya kepada alam sekitar, namun terdapat beberapa lagi teknolologi dan dasar lain yang berkesan boleh dilaksanakan untuk mengawal perlepasan gas ini ke atmosfera.

Dalam memenuhi permintaan tenaga, kadar pertumbuhan di negara ini juga sangat tinggi. Bahan api fosil mahupun nuklear tidak dapat menampung kadar

pertumbuhan ini. Jadi, satu-satunya penyelesaian untuk merasionalkan permintaan tenaga dan seterusnya mengawal pembaziran tenaga ialah dengan menggalakkan kecekapan tenaga.

Dalam bidang keselamatan tenaga, walaupun Iran mempunyai rizab minyak dan gas yang besar namun masih lagi berhadapan dengan banyak ancaman. Antara ancamannya adalah kadar pertumbuhan penggunaan tenaga yang tinggi, pergantungan ekonomi ke atas eksport minyak mentah, pembaziran tenaga, kurang pemerhatian kepada sumber-sumber biasa dan konflik politik. Jadi pembaharuan dasar tenaga perlu dilakukan untuk menyelesaikan masalah ini agar tidak melarat ke atas kemudahan nuklear.

Untuk menyiasat kos relatif elektrik yang dijana dalam setiap penjana alternatif, kos '*levelized*' elektrik mudah telah dipilih sebagai salah satu kaedah. Hasil kajian menunjukkan bahawa dalam keadaan semasa negara, kos elektrik di loji kuasa bahan api fosil akan lebih murah daripada nuklear.

Kesimpulannya, walaupun tenaga nuklear, termasuklah kitaran bahan api adalah hak Iran, pembinaan loji kuasa nuklear tidak akan menyelesaikan masalah kemampanan tenaga. Malah boleh menjadi pemangkin kepada kemerosotan kerana ia akan mengalihkan modal dan sumber keutamaan lain daripada projek-projek ekonomi seperti kecekapan tenaga, pembangunan berteknologi tinggi dan pengurusan sumber tenaga.

ACKNOWLEDGEMENTS

"**In the name of God, the most Beneficent and the most Merciful**"

The PhD research was conducted in the Department of Mechanical Engineering, University of Malaya. This research could not have been completed without the help of many people which I would like to appreciate to them now.

First, I wish to express my sincere gratitude to my supervisors, **Professor Dr. T.M.Indra Mahlia** and **Dr. Chong Wen Tong** for their valuable guidance and advices throughout the research. Their opinions on my research are extremely helpful in the making of the thesis a success.

I am very grateful to my wife, **Fatemeh** for her patience in putting up with me all through last three years. I also would like to give many special thanks to my **parents, sister and brothers** for their financial support and constant encouragement in my endeavor to complete my doctoral research. Without their support, I have not the opportunity to continue my study oversea.

Finally, I want to present this work to my lovely land **Iran**. I wish this research has a little share on the country's development to reach a better position it deserves.

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List of Symbols and Abbreviations

CEC	impact of carbon price on electricity cost	(\$/MWh)
CF	power plant capacity factor	(%)
CP	carbon price	(\$/ton CO_2)
CRF	capital recovery factor	
CV	calorific value	*(kcal/l)*
EF	emission factor in power plant	$(kg/m^3, kg/l)$
EG	electricity generation from power plant	*(GWh)*
EM	power plant emission	*(kton)*
EP	emission per unit electricity generation	*(kg/kWh)*
EX	exchange electricity with neighboring countries	*(GWh)*
FC	fossil fuel consumption	$(Mm^3, Ml, kton)$
FE	fuel consumption per unit electricity generation	(m^3/kWh, kg/kWh, l/kWh)
FT	fuel cost	(\$, \$/MMBtu)
HR	heat rate	(Btu/kWh)
I	investment and cash flow during construction	(\$)
k,C	constant values	
LEC	levelized electricity cost	(\$/MWh)
NC	power plant nominal capacity	*(MW)*

NP	share of nominal capacity	*(%)*
OCC	overnight capital cost	($/kW)
OMC	operation and maintenance cost	($, $/kW-year, $/MWh)
P	population	
PC	per-capita electricity consumption	*(kWh)*
PE	share of electricity generation	*(%)*
PF	share of thermal energy	*(%)*
PN	per-capita nominal capacity	*(W)*
R	interest rate	
SF	share of fuel emission	*(%)*
T	life time of power plant	(Year)
x	year predicted – year start	
y	predicted value	

Subscripts

f	fuel type consumed in power plant
i	in the year *i*
ng	natural gas
sf	substituted fuel

Superscripts

n	power plant type
p	emission type (CO_2, SO_2, NO_x and CO)
T	thermal power plants

Chapter 1 :

Introduction

1.1 Background

It is well known that there is a direct relation between electricity consumption and economic growth. Therefore, the electricity sector has to be developed to sustain this growth (Squalli, 2007). Like other developing countries, the majority of energy sources used in Iranian power plants are fossil fuels (IEA, 2008). More electricity generation in thermal power plants will increase fossil fuel consumption, which subsequently results in an increase in emissions. Increasing fuel consumption in power plants or other energy sectors such as domestic, industry, and transport will also cause rapid resource depletion and reduce energy exports as the major sources of the government’s income.

Based on the long-term energy plans, Iran wants to diversify its power plant types and utilization of alternative sources to achieve energy security. One of the recent types of power plant that Iran wants to develop is the nuclear power plant (NPP). Iran plans to construct enough NPPs to be capable of supplying 20,000 MW, in various parts of the country by 2025 to steadily meet the electricity demand, sustain the energy exporting ability of the government and decrease fossil fuel consumption by power plants. For the fulfillment of this requirement, the nuclear fuel cycle activities have been started by the Atomic Energy Organization of Iran (AEOI). Many research centers and divisions were established, and the technological and scientific infrastructures have been greatly enhanced.

Iran has decided to produce a certain amount of its future fuel needs through nuclear power plants. However, this policy causes some difficulties for the country because of the international community's concern in respect of Iran's nuclear fuel cycle activities. These concerns have led to four sets of United Nations Security Council (UNSC) sanctions and also some sanctions from the E.U. and U.S. over Iran's refusal to suspend uranium enrichment.

1.2 Research objectives

The first objective of this study is to obtain the pattern of many aspects of electricity generation in the Iranian power sector in last four decades and also its prediction until 2025. This objective includes number of power plant types, share of each type in the past and the future, base and peak load types and the share and overall amount of each fuel types consumed or probably will be used in the future. For future composition prediction, the government policy in the power sector and the trend of changes in this sector must be taken into account.

The second objective is estimating the total emissions due to electricity generation in the country in the past and also its prediction in the future. In general, thermal power plants operated by fossil fuels produce huge amounts of air pollutants and caused power sector as one of the major sources of air pollutants such as greenhouse gases in the country. To control the pollutant in this sector and also to be able to compare several types in view of emissions, it is necessary to have a clear view on the pattern of emission in power sector for each type of power plant. The pollutants that will be considered in this study are carbon monoxide (CO), sulfur dioxide (SO_2), carbon dioxide (CO_2) and nitrogen oxides (NO_x). Fuel consumption profile in Iran is significantly different from other developing countries, and this difference plays a significant role in defining the air pollutant's characteristics of power plants. Awareness of the amount of emissions per unit of electricity generation in each type of thermal power plant is necessary for the selection of the best plant type with regard to air pollutants and for assessing possible emissions in the future. In view of Iran's huge fossil fuel reservoirs, the dominance of fossil fuel based power plants in the future is predictable, and it is unlikely that the share of other types is likely to become significant soon. The effect of keeping the current composition and the new one which the government plans to introduce and the environmental effect of fuel switching to low carbon fossil fuels will be discussed too. As regards to fossil fuel reserves and dominance of thermal power plants, what will be the effect of energy policy and the government's plan on fuel consumption and emissions in the future? How much nuclear power plants can help to mitigate the emissions and fossil fuel consumption? Are there any capabilities such as renewable energy sources in the country to control the emissions and change the fossil fuel dominance? What are the shares of each fossil fuel types on emissions and how much can control the pollutants by switching to low carbon fuel types? The results will show how each strategy influences the emissions and fuel consumption in the future electricity sector of the country.

The third objective of the thesis is gathering all major threats of energy security in Iran. The current local and international circumstances and the government's energy policy must be taken into account to find and analysis the threats. It is necessary to find and present the policy suggestions to resolve or control any of the threats.

The fourth objective is to estimate the electricity price generated in each type of power plants in Iran. The types including, fossil-fuel based, nuclear, hydro power and also renewable energy sources. Because of lack in accurate financial data in the country and also many uncertainties, the main effort is to find a range of price by using the major electricity generation costs. Other minor costs also must be mentioned and the probable price based on the countries situation should be discussed.

Finally, the most important objective of the study is to investigate the effect of investing in nuclear power as an electricity generator in the country's power plant sector and generally on energy sustainability. Four key factors, including energy price, environmental issues, energy demand and security will be taken into account in this study. This study will try to determine whether or not nuclear energy is suitable for the country's energy sustainability and whether there are better ways for sustainability in respect of the four factors. This will be done after presenting the history of Iran's nuclear activities in the last four decades and its infrastructure, which has been developed for fulfillment of the government's energy policy.

To summarize, this study will try to answer these questions:

- What was the composition of the power sector in the last five decades, especially the pattern of fuel consumption, electricity generation and emissions?
- What will be the probable pattern of fuel consumption, electricity generation and emissions in the Iranian power sector in the future?
- Is electricity cost generated by nuclear power plants cheaper in comparison with thermal types in Iran?
- Can Iran survive without nuclear power plants or is there any better alternative to secure future energy demand?
- Are there any recommended projects to achieve energy sustainability in Iran? If so, in which order of priority should these projects be acted upon?

1.3 Limitations of the research

To determine the sustainable power plant composition, which is vital for the country many considerations should be taken into account. Among them, four important factors price, environmental issue, demand and security will be verified in this study. Another reason for considering these four factors is that they are the main criteria for developing nuclear power plants. Many believe that nuclear power is a clean energy that can increase energy security as well as meet the electricity demand and generate cheap electricity. This research is done based on the country’s current situation to verify these criteria. The present situation of the country may change in the future. For example, a change in the interest rate or finding new markets for natural gas will change the comparability of electricity price for different types of power plant. New or local technology can also change the situation of the energy sector of the country. There are also various internal and international political events that may change the situation in the future as well.

1.4 Significance of findings

Each country is in a unique situation to decide about its best energy strategy for all sectors, including electricity generation. In addition, according to their energy resources, technical and economic abilities they also have many options for their power plant composition. Because there are many alternative technologies and fuels available for this sector, it is important for policy makers to understand the implications of the different policies intended to meet the targets (Nakata, 2004). A comprehensive and optimized structure for the electricity generation to meet the needs of the country requires certain consideration. There are many criteria that are important for making decisions about the future electricity sector structure, such as job creation, energy demand, opportunities, military security, risk of project, environmental concerns and available technology. Fuel price, capital funds and environmental costs are also important factors to take into account in the electricity sector economic analyses. In addition, there may also be certain global factors such as carbon trading at the national and international level (Oh et al., 2010). Another important analysis for making decisions pertaining to energy options is the opportunity cost as the value of the next best alternative choice. As these sets of criteria are different for each country, energy decisions cannot be made on a ‘one size fits all’ basis. There is no unique answer for the optimal policy for all, and the strategy in each country depends on the respective situation.

Power plant type selection depends on the country’s energy policy. For some countries environmental issues are the first priority while for others the electricity price, energy security or even job creation are the main priorities. Understanding the results of this study will help the decision makers in the country to find a solution for energy sustainability. Moreover, the points that will be suggested can also help them determine the best options based on the abilities and constraints of Iran in the contemporary circumstances. They can optimize the strategy by changing certain policies, especially high-risk ones that are causing problems for the country. The results can also be used for other developing countries that want to use nuclear energy in their energy basket. These countries may be among the oil rich or those that import a major part of their energy. Both can simulate this study for their respective situations. The statistical importance of the thesis data is that the many energy related data collected. So researchers have the capability to use them in their research. The power sector data, such as fuel consumption, emission, electricity generation and pattern in last 42 years or even the forecasted data for next 16 years are all gathered in the thesis.

1.5 Original contribution

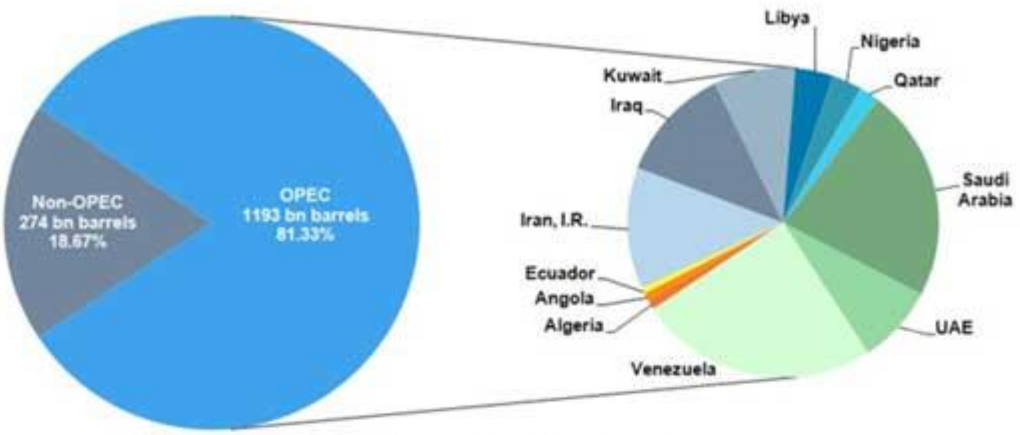
At this time when Iranian nuclear activities are considered controversial by international organizations such as the UN and IAEA, there are not many related scientific thesis. The conflict between two sides is mainly on uranium enrichment facilities. Iran pursues uranium enrichment because believes that nuclear energy is clean, cheap and can answer the energy demand and also helps energy security of the country. This policy and international sanctions made many difficulties for the country. This thesis investigates the country's situation and tries to suggest solutions to address the difficulties. Work in this field is imperative for international energy security and to decrease tension in this oil rich region. It is also essential and valuable to find a win-win solution to resolve the concerns of both sides. The author hopes to diminish tensions, which even may cause a war in the region by presenting scientific solution to achieve the main goals in the energy related field. The goals, which in the current circumstances may not be realizable through continuing nuclear activities. Although Iran has declared on several occasions that it's nuclear activities are for peaceful purposes, this study tries to develop certain recommendations and alternative ways for the energy sector of the country. If the activities are not peaceful, the problem would be changed, and it would be hard to find a logical scientific solution. Moreover, this study does not present the political or legal justifications but collects energy-related data for the country, including threats and opportunities to provide a wide view and facilitate careful consideration of the many aspects pertaining to energy sustainability in Iran. This study will also provide conditions for other researchers in Iran or similar developing countries in respect of energy policy to consider more factors or also verify the sensitivity effect of particular factors on energy sustainability.

Chapter 2 :

Literature review

2.1 Energy in Iran

Iran has an area of 1,648,195 km^2, with a population of about 75 million based on the latest census in 2011, 71% of which live in the urban area, and around 29% live in the rural area (Statistical Centre of Iran, 2012). The country is a member of OPEC (Organization of Petroleum Exporting Countries), which controls about 81% of the world's oil reserves and produces about 42% of the world's oil production. Iran is one of the major exporters of crude oil with approximately 10% of the world's oil reserves (151 billion barrels) (Figure 2-1) (OPEC, 2011).



OPEC proven crude oil reserves , end 2010
(billion barrels)

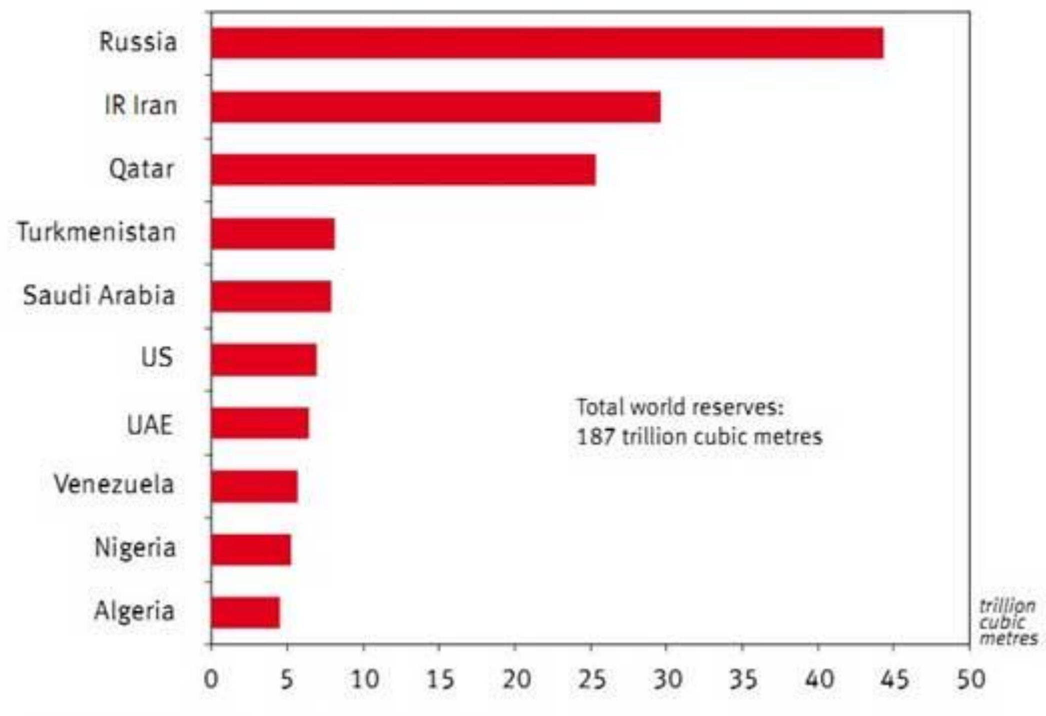
Venezuela	296.50	24.6%	Iraq	143.10	12.0%	Libya	47.10	3.9%	Algeria	12.20	1.0%
Saudi Arabia	264.52	22.2%	Kuwait	101.50	8.5%	Nigeria	37.20	3.1%	Angola	9.50	0.8%
Iran, I.R.	151.17	12.7%	United Arab Emirates	97.80	8.2%	Qatar	25.38	2.1%	Ecuador	7.21	0.6%

Source: OPEC Annual Statistical Bulletin 2010

Figure 2-1 OPEC proven crude oil reserves in 2010

Iran has the second largest reserves of natural gas in the world with approximately 19.7% of the world's proven natural gas reserves which are about 33,090 billion standard cubic meters (Figure 2-2) (OPEC, 2011). There are considerable undeveloped gas resources in the country such as the South Pars gas reservoir in the

Persian Gulf, which is equivalent to 6.7% of the total world's resources or around 62% of Iranian natural gas reserves (Energy Information Administration, 2010b; Hessari, 2005; Ministry of Energy, 2009c).



Source: BP Statistical Review of World Energy, 2010.

Figure 2-2 Natural gas reserves in 2009 (Top 10 countries)

It has been a century since commercial crude oil was discovered in Iran (Masjed Soleiman in the south-west of the country). Subsequently, the petrochemical industry has had a major influence on the political, economic, cultural and social aspects, as well as the security of the country. Since the industry was nationalized in 1953, crude oil exports have been the main source of the government's revenue upon which the country's economy is heavily petrochemical-product dependent. Nowadays, crude oil exports are the engine of the country's economic growth constituting 80% of the foreign exchange earnings, nearly 50% of the government budget revenue and about 23% of the GDP (Central Bank of Iran, 2010). In the last three decades, the consumption rate of all types of energy carriers in all sectors industry, transportation, agriculture and domestic has been higher than energy production. Figure 2-3 shows the total energy production, exports and consumption in the country from 1967 to 2009 (Institute for International Energy Studies, 2011; Ministry of Energy, 2011).

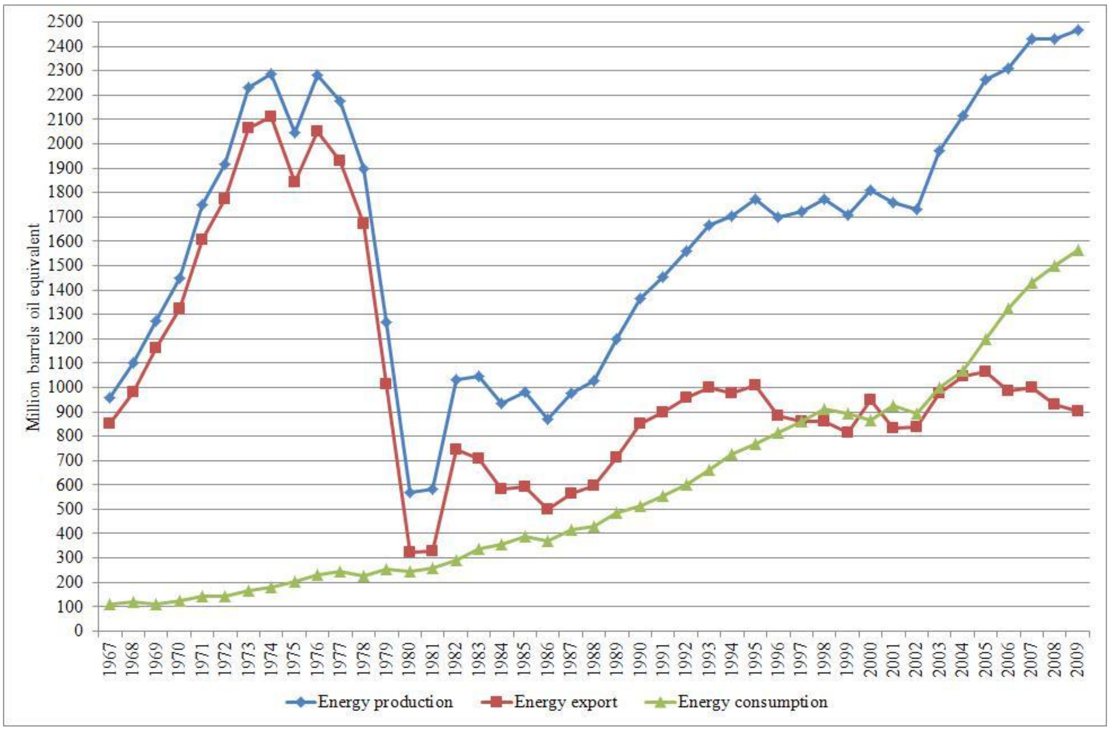


Figure 2-3. Total energy production, exports and consumption in Iran from 1967 to 2009

Crude oil plays an important role in the economy as well as the energy system of the country, constituting more than 44% of Iran’s primary energy consumption in 2009. Furthermore, although its production fluctuated from time to time, the majority of energy exports have always been crude oil. After the first global oil crisis in the early 1970s, oil exports increased and reached about 5.4 million barrels per day (mob/d) in 1976. During 1978-1981, due to the strike by oil workers and uncertainty brought by the Islamic revolution, crude oil exports rapidly decreased to about 0.9 mob/d. Since then, some internal and international events, such as the Iraqi invasion and U.S. sanctions, have prevented Iran from financing and developing petroleum resources, which has inevitably led to a decline or minimal growth in the country’s oil production.

Consequently, crude oil exports have shown small growth and reached about 2.5 mob/d in 2009. Figure 2-4 shows the crude oil production, exports and consumption in the country since 1967 (Energy Information Administration, 2011; OPEC, 2010).

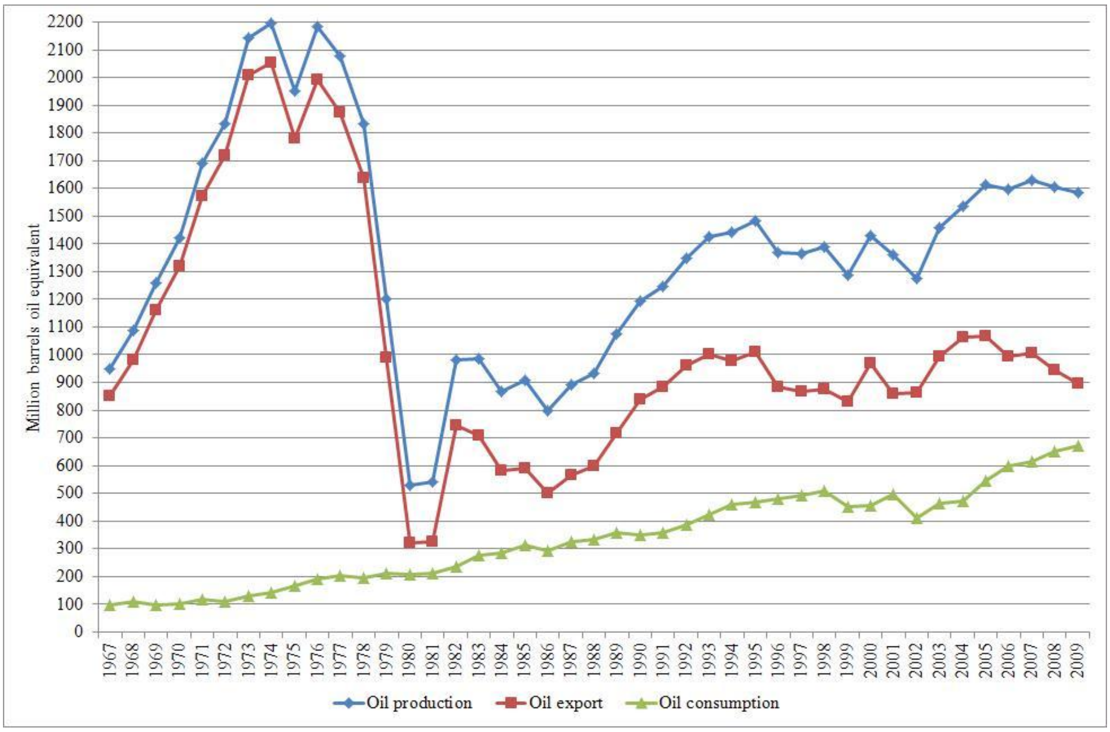


Figure 2-4 Total oil production, exports and consumption in Iran from 1967 to 2009

Iran has the second largest natural gas reserves in the world, with estimated reserves of about 33,090 billion standard cubic meters (OPEC, 2011). In the last three decades, natural gas recorded the fastest growth, with an increase in production of 14.7 times. At the same time, its contribution to the country's primary energy supply increased from 12% in 1979 to 56% in 2009. Even though natural gas production increased quickly, Iran was an importer of its natural gas needs in some years due to the high consumption rate. Figure 2-5 shows the natural gas production, exports and consumption in Iran from 1967 to 2009.

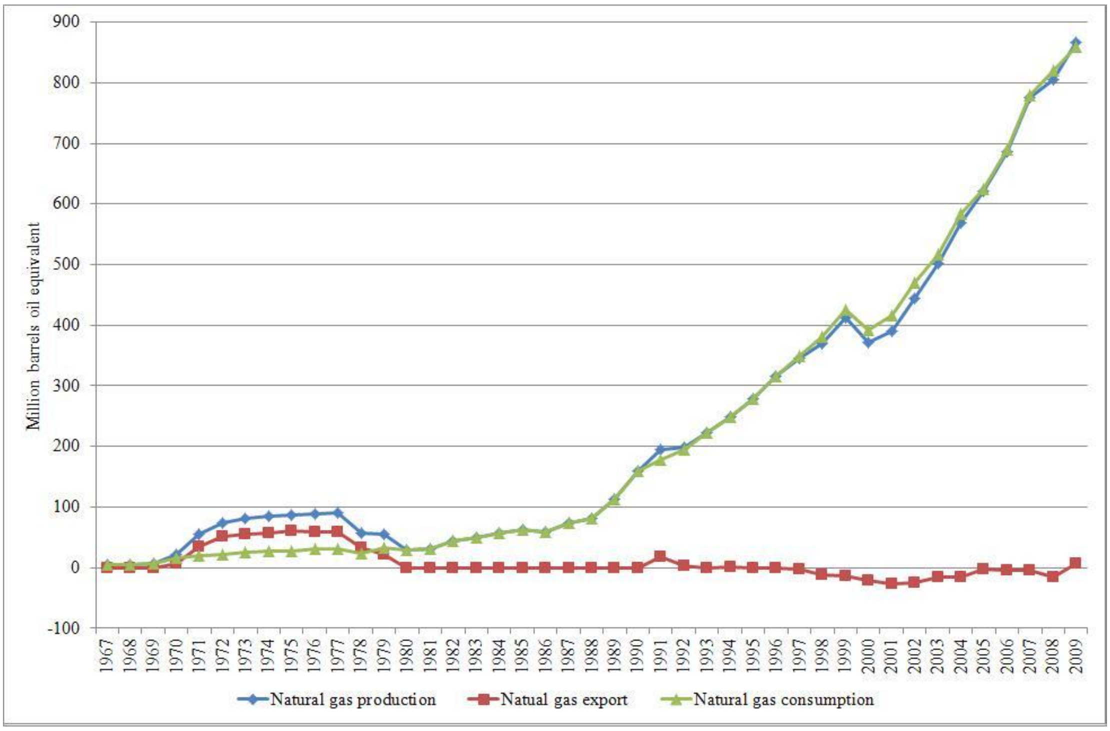


Figure 2-5. Total natural gas production, exports and consumption in Iran from 1967 to 2009

In 2009, Iran consumed about 1,544 million barrels of oil equivalent energy (Mboe) from fossil fuels in all sectors which was about 63% of total energy production in the country. The share of each sector's energy consumption in 2009 is shown in Figure 2-6.

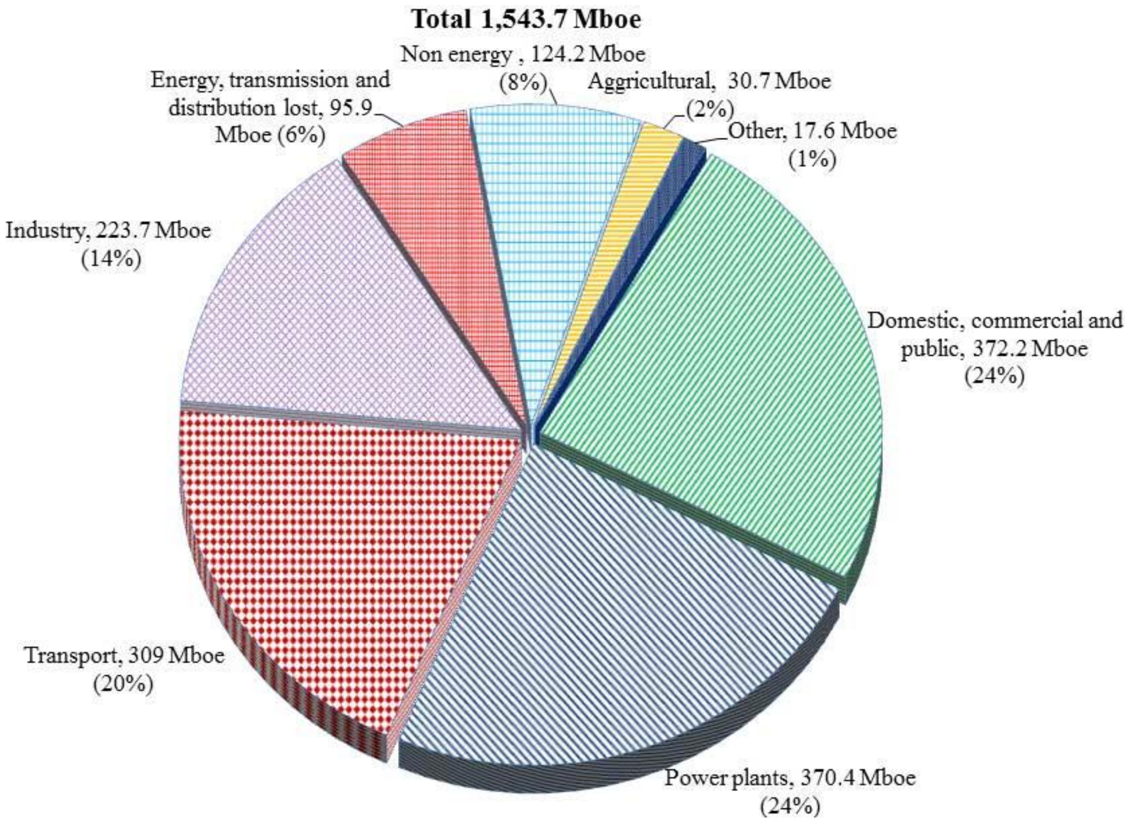


Figure 2-6 Amount and share of each sector in the fossil fuel energy demand in 2009

The highest energy consumption sectors in Iran are domestic and power plants, which together consume half of the country's total energy. This is followed by transportation, industry, non-energy sector, the energy sector, and agriculture, respectively. The consumption of each energy carrier, including electricity, petroleum, natural gas and coal, in all sectors, for 2009, is shown in Figure 2-7.

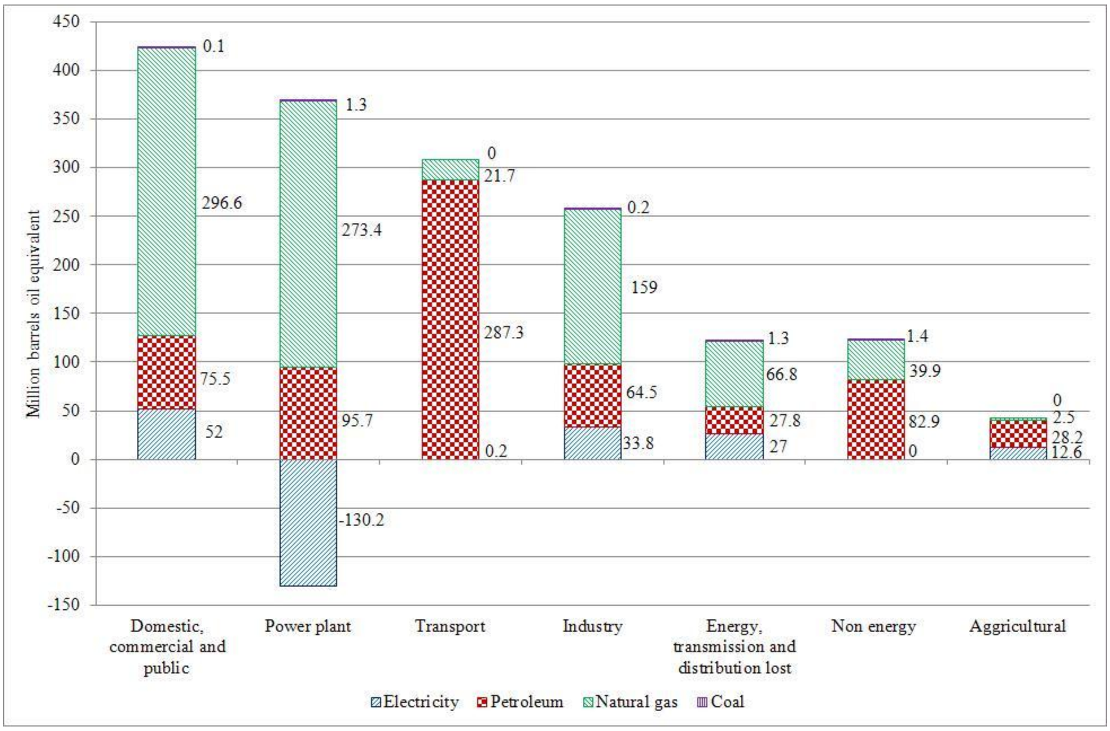


Figure 2-7. Energy consumption in each sector by the source of energy in 2009

2.2 Power plant sector in Iran

The power industry in Iran, including power generation, transmission and distribution facilities, is owned, operated and administered by the Ministry of Energy (MOE) through its executive organizations, which include TAVANIR (Power Generation and Transmission Management Organization) and the regional power companies. The majority of nominal capacities and electricity generation in Iran is from three types of thermal power plants; Gas turbine, combined cycle and steam turbine. In 2009, the power plant sector used 374.8 Mboe (equivalent to 24% of total primary energy) including 95.7 Mboe from oil, 273.4 Mboe from natural gas, 1.3 Mboe from coal and 4.4 from renewable sources to generate electricity equivalent to 130.2 Mboe. Approximately 27 Mboe of electricity was lost in transmission and distribution networks or consumed by the power plants directly. The remaining (103.2 Mboe) was exported (2.4 Mboe) or consumed by final consumers in all of the other sectors. The highest electricity consumer sector is the domestic, accounting for about 50% (52 Mboe), while industry accounts for 33% (33.8 Mboe). Figure 2-8 shows the energy flow of the power plant sector in Iran in 2009 (Ministry of Energy, 2011).

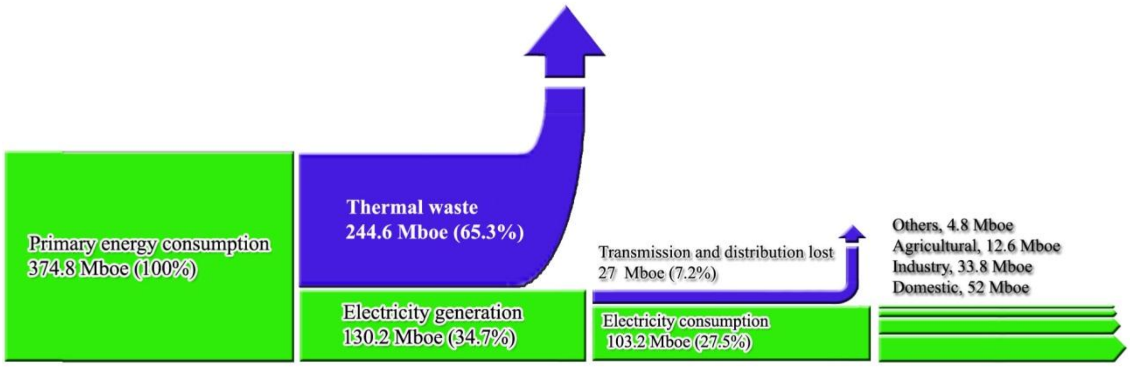


Figure 2-8. Energy flow of the power plant sector in 2009

2.2.1 Fossil fuel based power plants

At present, most of the Iranian power plants are using fossil fuels or non-renewable sources such as natural gas, fuel oil and diesel to generate electricity. These power plants are steam turbine, combined cycle, gas turbine and diesel engine.

Steam turbine power plants

The steam turbine type is a base-load power plant. It produces steam of high purity, high pressure and at a high temperature, which causes the steam turbine to drive the electric generator. In 2009, steam power plants have 15,598 MW nominal capacity, which is equivalent to 29.5% of total nominal capacity and produces 45.4% of the total electricity generation in the country. The efficiency of these power plants in Iran is about 36% (Ministry of Energy, 2009b).

Gas turbine power plants

Gas turbines are open cycle and do not use water for operation, and require little time (2-3 years) to build. Gas turbine power plants are sometimes installed as emergency generators. They are mainly used at peak-load or in places that are difficult to find water resources to use for steam power generation; their thermal efficiency is about 29% (Ministry of Energy, 2009b). Today, gas turbine power plants in Iran have a nominal capacity of approximately 18,077 MW, which is equivalent to 34.1% of the total capacity and produce 25.6% of the total electricity generated in the country.

Combined cycle power plants

Combined cycle power plants are based on the structure of the simple gas turbine with steam units added to use the residual heat of the flue gasses. This type of fossil fuel power plant uses the gas turbine in conjunction with a heat recovery steam generator (HRSG). It is referred to as a combined cycle power plant because it combines the Brayton cycle of the gas turbine with the Rankine cycle of the HRSG. This type of power plant has a capacity of 13,664 MW nominal, which is equivalent to 24.3% of the total nominal capacity and produced 29% of the total electricity generated in the country in 2009. The thermal efficiency of these plants in Iran is about 44% (Ministry of Energy, 2009b). The maximum efficiency of combined cycle plants reached a record heat rate of 5690 Btu/kWh, or just under 60%, at a facility in Baglan Bay, Wales (General Electric Company, 2009).

Diesel engine power plants

The purpose of diesel engine power plants is to provide back up power for hospitals, water pumps and industries that need to ensure a reliable power supply at all times. Today diesel engine power plants represent some 10–15% of the total installed capacity all over the world but constitute less than 0.1% in Iran (Kanoglu et al., 2005). The efficiency of this type of power plant in Iran is about 32% (Ministry of Energy, 2009b).

Fossil fuel consumption in thermal power plants

The type of fuel used for power plants depends on many factors, especially the economic, politic and technical parameters. These parameters include the cost of the fuel, geographical location of the power plants, availability of the fuel, environmental concerns and medium and long-term policies of the energy sector. For example, the fuel type used in thermal power plants in India and China are mainly coal (Perkins, 2005; Zhang et al., 2007). In Iran, fossil fuels such as fuel oil, diesel and natural gas are the main fossil fuels used in thermal power plants. However, mostly the power plants use natural gas as a primary-fuel, except for diesel engines and the power plants that are located far from national gas pipelines. There are also emergency backup fuels for power plants. For example, in the winter when the residential usage of natural gas is maximized, due to the pressure drop in the national gas pipeline, some power plants switch their fuel type. The substitute fuel for steam power plants is fuel oil, and for gas turbine and combined cycle power plants it is diesel oil. Diesel oil is a unique fuel for diesel engines and is only used at the starting stage for steam power plants. The types of fuel consumed in Iranian power plants are presented in Table 2.1.

Table 2.1. Fossil fuel types use in Iranian thermal power plants

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Natural gas	x	x	x	-
Diesel	x	x	x	x
Fuel oil	x	-	-	-

x = fuel is consume in power plant, and **(-)** = fuel is not consume in power plant

2.2.2 Renewable energy power plants

Renewable energy is generated from renewable resources such as wind, solar, hydro and geothermal. The ecological and geographical characteristics of Iran are well suited to a diverse and extensive use of renewable energy sources. In addition, the demographically diverse large population in scattered and remote areas with different climates dictates the use of all sources of renewable energy in Iran for better and equitable access to energy (Mostafaeipour et al., 2009). Non-hydro renewable energy comprises about 5% of global power generating capacity and supplies about 3.4% of global electricity production (REN21, 2007). At this time, Iran is using renewable resources such as hydro and wind to generate electricity.

Hydropower plants

Hydropower is more expensive initially but provides continuous supply of electricity with high efficiency and a longer life span of the associated infrastructure. It considerably reduces energy losses, enhances network stability and provides a higher availability factor compared to the other types of power plant if adequate water resources are available.

The average annual rainfall of Iran is about 250mm, compared to the world (with an average annual rainfall of 750 mm) Iran is considered a dry country (Mohammadi, 2011). Therefore, it is natural that Iran is unable to use all its hydropower capacity. For example, in 2008, only 2.2% of electricity was generated using hydropower plants, even though these plants had 14.5% of the total nominal capacity (Ministry of Energy, 2009c).

Wind turbines

Iran has a large wind potential due to its geographical location (Ministry of Energy, 2008a). This is a scientifically reliable for both offshore and onshore regions. This potential for wind power generation and supplying to the national distributing network, could offer many advantages including job creation in the country. In recent years, Iran has made considerable progress in utilizing wind energy. Up unto the end of

2008, 113 wind turbines were installed in several regions of the country with a total capacity of 63MW.

2.3 Future power plant composition

For sustainable development and to increase energy security, the Iranian government plans to fulfill many energy-related projects and increase power plant diversity. The country is currently launching and developing new energy sources such as nuclear, coal and more renewable energies like solar thermal, solar photovoltaic, geothermal, biomass, bio-gas, hydrogen, wave and fuel cells, which are all undergoing feasibility studies or still under development (SUNA, 2009). In addition, in recent years, several actions have been taken in order to increase the efficiency and capacity of power generation, such as empowering gas turbines for some plants, removing the limits on some generation units and equipping the gas turbines of combined cycle power plants with cooling systems for inlet air (Niroo Research Institute, 2008). The installation of steam turbine units next to gas turbines has been carried out in many power plants in order to achieve a combined cycle. This has resulted in higher efficiency of the unit, less consumption of fuel, and, consequently, lower release of emissions. Power plant modernization and performance improvement has also raised the share of the combined cycle type causing an increase in the total thermal efficiency. The average efficiency of Iranian power plants in the past 30 years increased from 26% to 37% (TAVANIR, 2009a). Therefore, there will be less fuel consumption to generate a unit of electricity compared with the old power plants. However, in light of according to Iran’s huge oil and gas reservoirs, the dominance of fossil fuel based power plants in the future is predictable, and it is unlikely that the share of the other types will become significant in the near future.

Details of the potential government goals for changes in fuel source composition and development of the electricity sector were collected from various sources and described in the following sections. Despite all the technical, economic, and political limitations that Iran may face in achieving the goal, these are considered as the likely composition of Iran's future power plants.

2.3.1 Fossil fuel based power plants

Steam turbines

Due to the high investment required for the construction of steam turbines, there has not been much new development of this type of power plant in recent years. The capacity of steam power plants in 2004 was 15,229 MW, but with less than 1% annual growth only reached 15,704 MW in 2009. It is expected that this trend will continue in the coming years, and its share of the capacity and electricity generation will be less than before. Other reasons for the lack of development of the steam power plant are that they are base-load plants, and it is expected that in the coming years more concentration will be focused on peak-load power plants. In addition, the construction of nuclear power plants which is a kind of base-load plant, has contributed to the decrease in the share of steam power plants (TAVANIR, 2009b). In this study, the steam power plant capacity in the future is considered the same as the capacity in year 2009.

Diesel engines

The share of diesel engine power plants in Iran's power capacity and also in electricity generation, decreased from 21% to less than 1% since 1967. The policy not to construct a new capacity for diesel engines is due to the fuel prices and pollution problems. In this study, no more investments are envisaged for this type of power plant, and its total capacity is considered to remain at 425 MW as in 2009.

Coal-fired

Iran has no coal-fired power plants at the moment, however, having the resources of coal, has made it start a coal-fired power plant in Zarand region and it plans to increase its capacity after commissioning 5,000 MW in the long-term (Ministry of Energy, 2009a). In this study, the capacity of 5,000 MW is considered for this type of power plant in 2025.

Gas turbines and combined cycles

The gas turbine power plants can be used in the rapid operation when the electricity demand is at its peak. When considering fuel prices, gas turbine power plants have an economic justification, however, from the viewpoint of national interests, it is one of the major energy policies in the country to make use of this fuel type at higher efficiency as combined cycle power plants (TAVANIR, 2009b). Accordingly, the government plans to launch 27 steam units for the existing gas turbine power plants, and many of them will become the combined cycle type (TAVANIR, 2009a). Since 2000, the share of the combined cycle and gas turbine type has grown rapidly, and probably these types will have the largest share of electricity production in the country in the future. In this study, the capacity of gas turbines and the combined cycles in the future are considered to be equivalent to the remaining capacity needed after the consideration of all other types.

2.3.2 Hydropower plants

Hydropower plants do not discharge air pollutant emissions during operation and provide cheap electricity production and other benefits. In addition, due to the flexible operation, they are important for network stability. In recent years, despite a drought which has reduced their share of electricity generation, the construction process of hydropower plants has increased and several huge projects are under feasibility, study and construction. Based on the country's 20-year vision plan (2006-2025), the entire hydropower capacity should be extracted and exploited (MehrNews Agency, 2008). Figure 2-9 shows the capacity growth of hydropower plants in the country (Iran water & power resources developement Co., 2009).

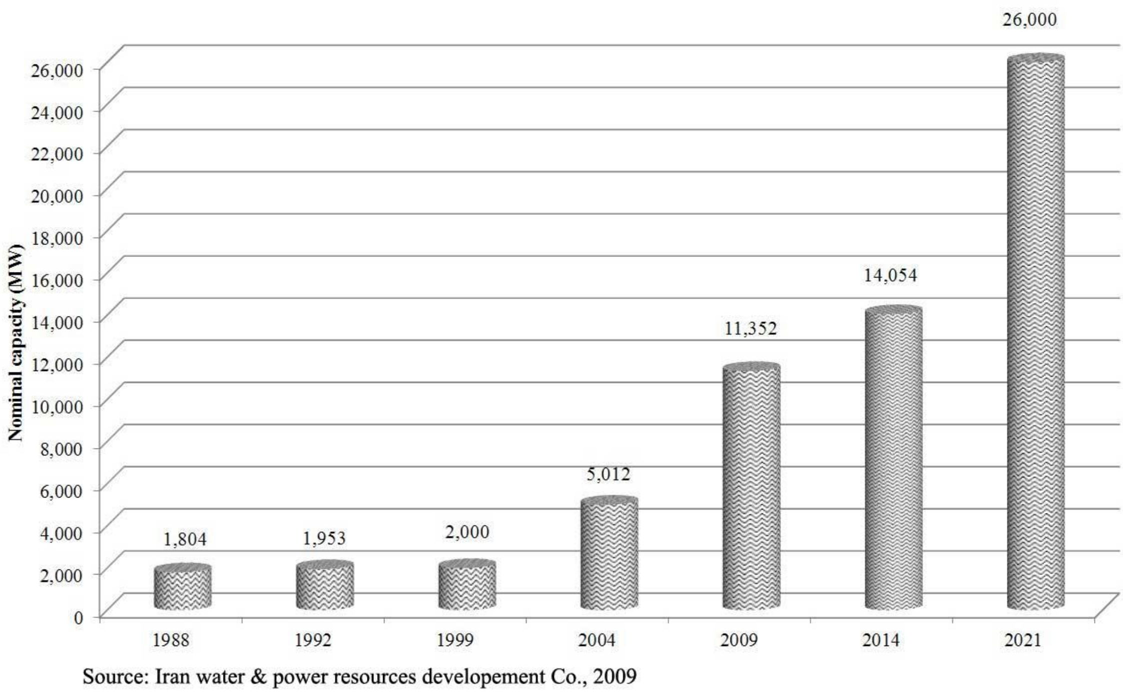


Figure 2-9. Iranian hydropower plants nominal capacity

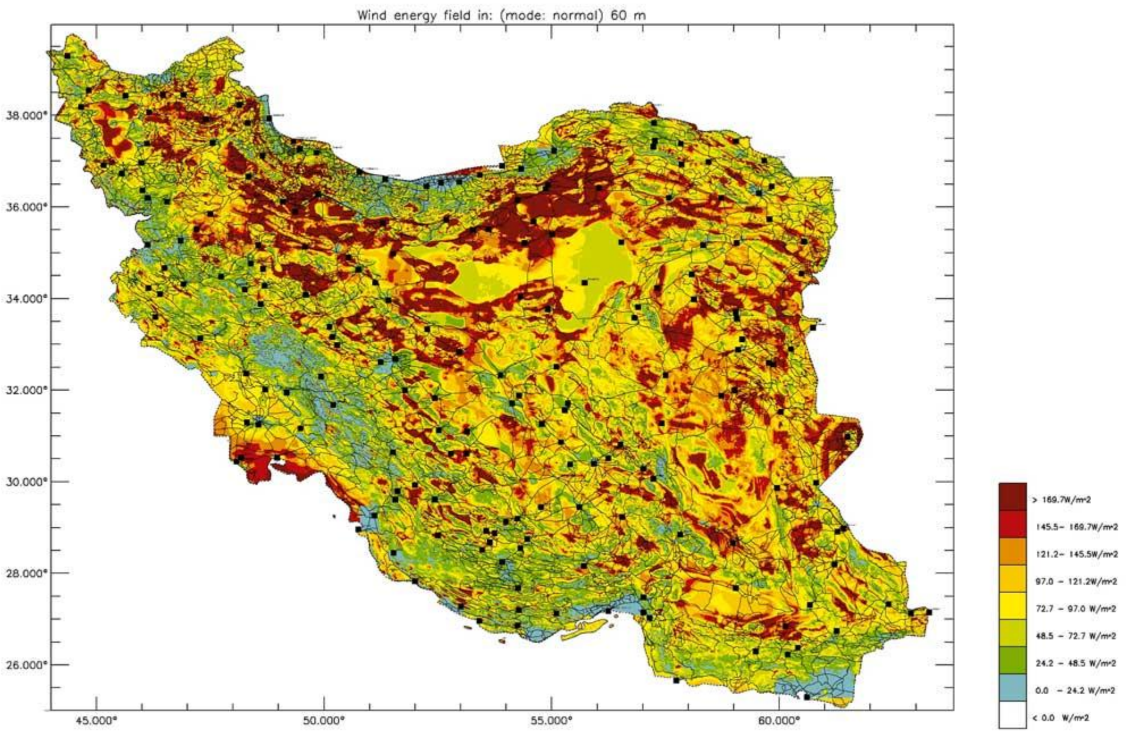
2.3.3 Non-hydro renewable energies

Although most of the Middle East countries are rich in fossil energy resources, the use of Renewable Energy Sources (RES) has started to be of interest to the scientific community and government (Mostafaeipour & Mostafaeipour, 2009). Energy Information Administration (EIA) predicted that renewable energies are projected to account for a modest 3% of the Middle East total electricity generation by 2030 (Energy Information Administration, 2009).

Iran is a developing country with a high rate of electricity consumption. In order to secure the supply of electrical energy, renewable energy should play an important role in helping the sustainable development, especially in Iran where most different types of RES are available and are also possible to implement to acquire the required energy supply (Ghobadian et al., 2009). According to the objectives of the fourth 5-year plan, the government will increase the share of electricity production from these sources to 1% (PENN, 2008). The government policy to purchase electricity produced from renewable resources from the private sector will encourage investment in this sector. Furthermore, because of reduction in the costs due to technological development, it is expected to speed up the growth to achieve the goal as soon as possible (Ministry of Energy, 2009c). In Iran, the renewable sources of energy including wind, solar and geothermal will account for 3% of the country's nominal electricity generation capacity (Ministry of Energy News Agency, 2010).

Wind energy

Due to Iran's geographical location, it has a good potential for the production of electricity using wind energy. The renewable energy organization of Iran (SUNA) has provided a national wind map (wind atlas), as shown in Figure 2-10 (Renewable Energy Organization of Iran, 2010). The total potential for wind power was initially estimated as 30,000 MW (GWEC, 2006). In recent years, various activities have been done to implement wind energy for the generation of electricity, and the application of wind energy has been developed very fast (Ameri et al., 2006). Since 2001, the use of wind energy has been growing rapidly, and its capacity has increased 30% annually and reached 92 MW in 2009. Finally, based on the next country's development plans, 2,500 MW of wind turbines will be developed (TAVANIR, 2009a).

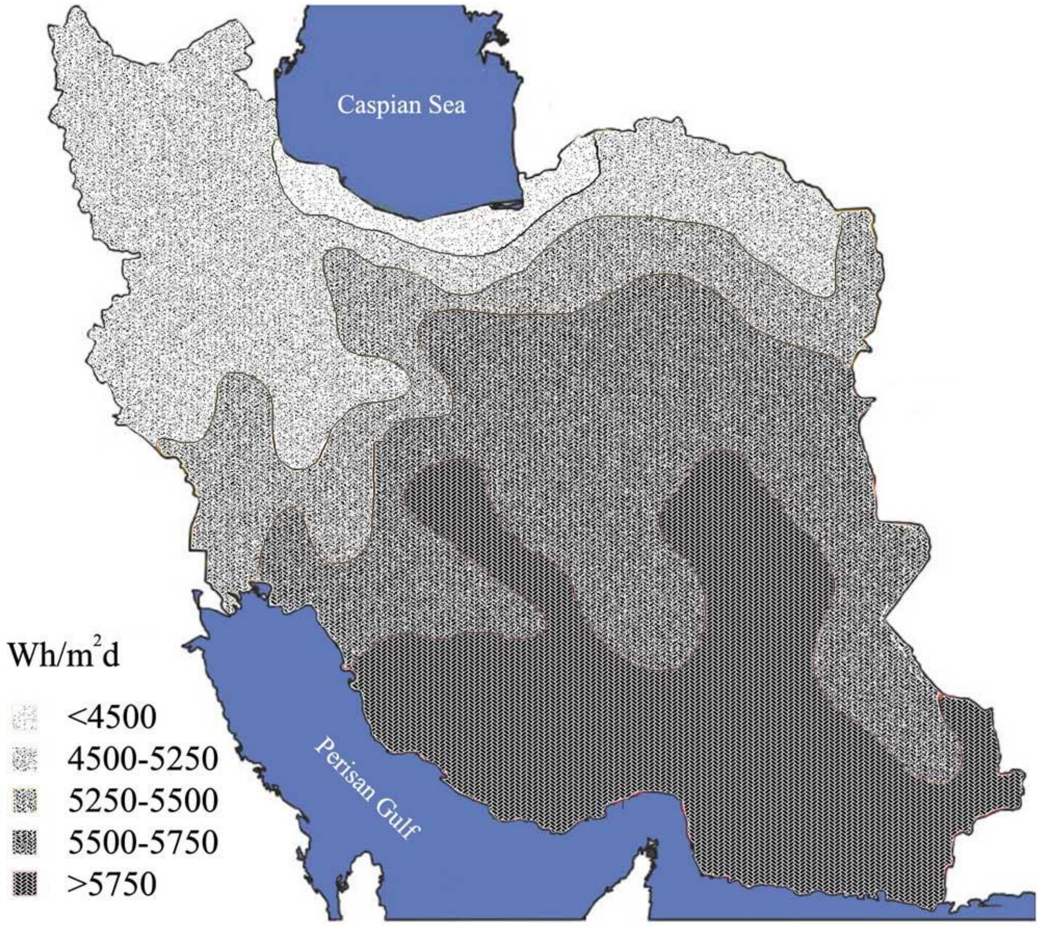


Source: Renewable Energy Organization of Iran, 2010

Figure 2-10. Wind atlas map of Iran

Solar energy

The average solar radiation for Iran is about 5.3 *kWh/m²/day* and it is even higher in the central region of Iran, with more than 7.7 h/day (more than 2,800 h/year), as depicted in Figure 2-11 (Center for Environment and Energy Research and Studies, 2005; Ministry of Energy, 2008b). The first integrated solar combined cycle system (ISCC), which is the biggest of this type of power plant in the Middle East, is under construction in Yazd. Technical and economic assessment has shown that this is the most suitable project for renewable energy sources in Iran (Hosseini et al., 2005). The great amount of solar energy potential and environmental interest are among the main considerations that led the Ministry of Energy to define, support and install the first 250 kW pilot solar thermal power plant in Shiraz (Ministry of Energy, 2009c; Yaghoubi et al., 2003). The Center of Renewable Energy Research and Application (CRERA) and Atomic Energy Organization of Iran (AEOI) has conducted and completed many research projects in the area of solar energy. For example, the design and simulation of solar water pumps, solar water distillation of various types, design, manufacture, and simulation of solar collectors of different types, solar refrigerator and design and the manufacture of solar air heaters (Ghobadian, et al., 2009).

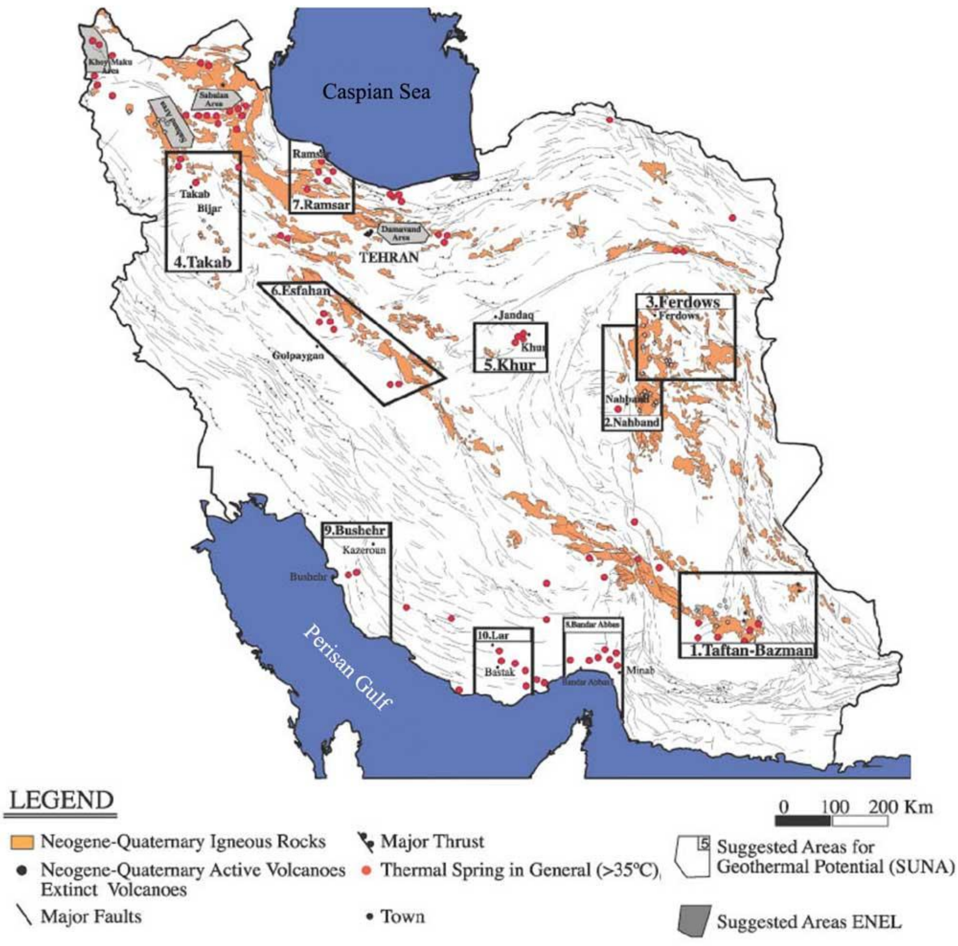


Source: Center for Environment and Energy Research and Studies, 2005.

Figure 2-11. Solar radiation in Iran

Geothermal energy

It is indicated that 8.8% of Iran has prospects for geothermal power plants with potential for about 18 fields (Noorollahi et al., 2009). The internal geothermal energy has been estimated to provide about 1400 MW of power for the consumers in Iran (Fadai, 2007). Studies by CRERA showed that ten promising areas have been identified throughout Iran since 1995 (see Figure 2-12) (Lavizeh, 2002). The Ministry of Energy has started building the first geothermal power generation in one of these areas in Meshkinshahr in the North West of Iran. It is predicted that in phase I, about 5 MW and in phase II, about 55 MW electricity will be produced from these projects (Ministry of Energy, 2009c).



Source: The Center of Renewable Energy Reseach and Application, 1995

Figure 2-12. Geothermal potential of Iran

2.3.4 Nuclear power plant

Nuclear power plants (NPP) have some advantages in comparison with fossil fuel types. They are a base-load type, which helps networks in terms of stability, as well as decreasing the emissions of greenhouse gases. Moreover, the price of nuclear fuel is comparatively stable, while not requiring much space to store. Someone compare benefits of nuclear electricity with other alternatives in their countries. For example, (de Carvalho et al., 2009) compared construction of new nuclear power with hydro power in Brazil and showed that nuclear has not priority for expand power generation and large scale hydro power plants are cost effective than nuclear. Brazil has a huge hydro power potential around 261 GWh, which merely 27% of them are in use. His study shows that using more hydro power and also optimizing the energy sector with conjunction with fossil fuel power plants is the best solution for Brazil's situation.

Nuclear energy has been used to produce electricity for more than 50 years. In 2007, it provided about 17% of the world's electricity supply, 23% in the Organization for Economic Co-operation and Development countries (OECD) and about 30% in Europe. Currently, around 438 reactors, representing a total capacity of 372 GW (2,719 TWh) are in operation in the world, and 54 reactors are still under construction (International Atomic Energy Agency, 2010; International Energy Agency (IEA), 2010; Lior et al., 2007). According to the IAEA's 2006 projections, the world nuclear power capacity is expected to expand to a minimum of 414 GW in 2030 and a maximum of 679 GW according to the high estimates (International Atomic Energy Agency, 2007). According to Gorashi, Iran needs 15 GW nuclear power plants to be constructed within 30 years to secure a sustainable energy development (Ghorashi, 2007). Based on other reasons the need for energy, superior technology achievement, creating diversity, energy security, and environmental advantages nuclear power plant development is considered by some as a necessity for the long-term plan for energy supply (ISCA Agency, 2009).

Based on the long-term energy plans, Iran wants to diversify its power plant types and utilize alternative sources to achieve energy security. One of the recent power plant types that Iran wants to develop is nuclear power plant (NPP). The idea of building NPP in Iran is not new. In the mid-1970s, a major nuclear power program was recommended to Iran by the U.S.A. based on the future energy needs of the country. This study was carried out at Stanford University. The proposed NPP began by the construction of two 1,200 MW NPP at Bushehr supervised by Kraftwerk Union AG (KWU), a subsidiary of Siemens. The Bushehr NPP unit 1 reactor was 85% complete prior to the Iranian revolution, and was due to be completed in 1981, however in 1979 (after the revolution) the construction program was suspended. In 1995, the Atomic Energy Organization of Iran (AEOI) and the Ministry of Atomic Energy of the Russian Federation (MINATOM), signed a contract on the scope of work for completing the Bushehr NPP unit 1 with a 1000 MW pressurized water reactor (PWR) (IAEA, 2009). The launching of this power plant was postponed several times, however, the nuclear fuel was finally transferred in Aug 2010, and will probably be generating electricity by early 2011 (Worldnews, 2010). In line with the construction of 1,000 MW pressurized water reactor type at Bushehr with Russia’s assistance, Iran is planning to operate a nuclear power plant of 360 MW using local technology (TAVANIR, 2009b). In addition, construction of 5,000 MW of nuclear power plants is considered as a goal in the fifth 5-year national development plan (started 21 March 2010). Following the trend in the sixth and seventh country's 5-year plans by 2025, nuclear power plants will supply 10% of the electrical energy needs of the country equivalent to 20,000 MW (MehrNews Agency, 2009). The main goals of Iran are to meet the electricity demand, sustain the energy exporting ability for the government and decrease the fossil fuel consumption by power plants. For the fulfillment of these requirements, the nuclear fuel cycle activities have been started by AEOI. Many research centers and divisions have been established, and the technological and scientific infrastructures have been greatly enhanced (World information service on energy, 2010; World nuclear association, 2010a).

However, as the time for the commissioning of the Bushehr nuclear power plant has been prolonged, it is not clear as to whether a 10% supply of electricity needs from nuclear power by 2025 is realistic. In addition, further concerns of the international community in respect of the Iranian nuclear activities and the imposition of various sanctions, has increased the economic, political and social costs to execute the plan (World Nuclear Association, 2010b). Nevertheless, in this part of study, the government targets on constructing 20,000 MW nuclear power plants by 2025 is considered as the capacity for this type of power plant.

Uranium resources in Iran have not been fully researched, but it is speculated to range between 700 and 1,400 tons (for extraction cost less than 260 US$/kg) (Ministry of Energy, 2011). At the moment, the majority of uranium used in Iran is imported (IAEA, 2009). Iran has a uranium mine in Saghand and is capable of producing yellowcake by milling uranium ore in another mine in Gachin near Bandar-Abbas. It has also been able to turn yellowcake into UO_2 and then to UF_6 gas in the Esfahan nuclear technology center as well as enriching this gas to increase the amount of U-235 at the fuel enrichment plant in Natanz. The final stage of the chain is converting UF_6 back to UO_2 and into ceramic fuel pellets, which Iran plans to do in the Esfahan nuclear technology center. Iran has considered two storage sites in Anarak and Karaj for depositing the used fuels in the future.

Nuclear fuel cycle in Iran

Nowadays, although 32 countries are generating electricity using NPPs, only 8 of them have industrial nuclear fuel production for their own consumption or for export. Other countries do not have it because of economic, technical or political reasons. Iran has some justifications for producing some parts of its future nuclear fuel needs. First, it plans to construct NPPs capable of generating 20,000 MW NPP, which will supplement 10% to 20% of its energy needs and it hopes to be at least partially independent when it comes to nuclear fuel. Second, although it has had some share in the enrichment factories or uranium mines abroad since 1975, it has faced some difficulties in the past in terms of accessing nuclear fuel or having laboratory facilities to conduct experiments (Reuters, 2010). Consequently, to resolve these concerns Iran has successfully developed all the elements of the nuclear fuel cycle itself by constructing many nuclear facilities to achieve independence. This has led to the indirect consequences of Iran developing an indigenous nuclear fuel cycle that is capable of supplying and sustaining its own NPP. The list of facilities in the design, operating or under construction phases in the country are tabulated in Table 2.2 and shown in the country’s map in Figure 2-13 (AEOI, 2009; Nuclear Threat Initiative, 2010; The Institute for Science and International Security, 2010; World nuclear association, 2010a).

Table 2.2. Iranian nuclear capabilities

Location	Capability
Anarak	Waste storage site
Arak	Hot cell facility for production of radioisotopes Heavy water production plant
Ardekan	Uranium mine
Bandar-Abbas (Gachin)	Uranium mine yellowcake production
Bushehr	Nuclear power plant
Darkhovin	Nuclear power plant (under design)
Esfahan	Nuclear technology center Miniature neutron source reactor Light water sub-critical reactor Heavy water zero power reactor Fuel fabrication laboratory Uranium conversion facility Fuel manufacturing plant
Karaj	Radioactive waste storage
Lashkar Ab'ad	Pilot uranium laser enrichment plant
Natanz	Pilot fuel enrichment plant Fuel enrichment plant
Qom (Fardo)	Semi-industrial uranium enrichment
Saghand	Uranium mine
Tehran	Nuclear research center Molybdenum, Iodine, and Xenon Radioisotope production facility Jabr Ibn Hayan multipurpose laboratories Waste handling facility

Figure 2-13. Iranian nuclear facilities

Nuclear energy in the Persian Gulf region

In recent years the interest in nuclear energy in the region has become widespread. Other petroleum-rich countries in the south of the Persian Gulf have signed agreements to proceed with nuclear development. There are also other countries in the Middle East and North Africa that have expressed interest or conducted studies related to nuclear energy. They want to supply some parts of their future needs of electricity and to process heat for industrial applications, especially seawater desalination using nuclear energy (El-Genk, 2008; Murphy, 2007). The main goal of developed countries in supporting petroleum-rich countries in this way is to keep them assured of primary energy exports in the future while creating two-way dependency on nuclear and fossil fuels. The same situation happened about four decades ago in Iran when its population was one-third of what it is today, and when it produced 5 to 6 mob/d oil with only 10% for domestic use. At that time, the developed countries helped Iran to construct much of its infrastructure and proposed the development of some thousands of MW of nuclear electricity.

Chapter 3 **:**

Methodology

3.1 Introduction

In this chapter, the outline of the methodology employed in the study is presented. As shown in Figure 3-1, there are many methodologies used in this study. There is a mathematical method to find unavailable data in the past, analyze trends and estimates for future data. The methodology is to analyze the power sector composition. There are many equations for verifying various aspects of the power sector such as capacity, generation, fuel consumption and emissions. The levelized electricity cost is also selected as a methodology to estimate the electricity price in power plants. All the collected data used in this study is presented in separate tables at the end of this chapter. The data are related to the Iranian power sector over the last 43 years such as power capacity, generation and fuel consumption.

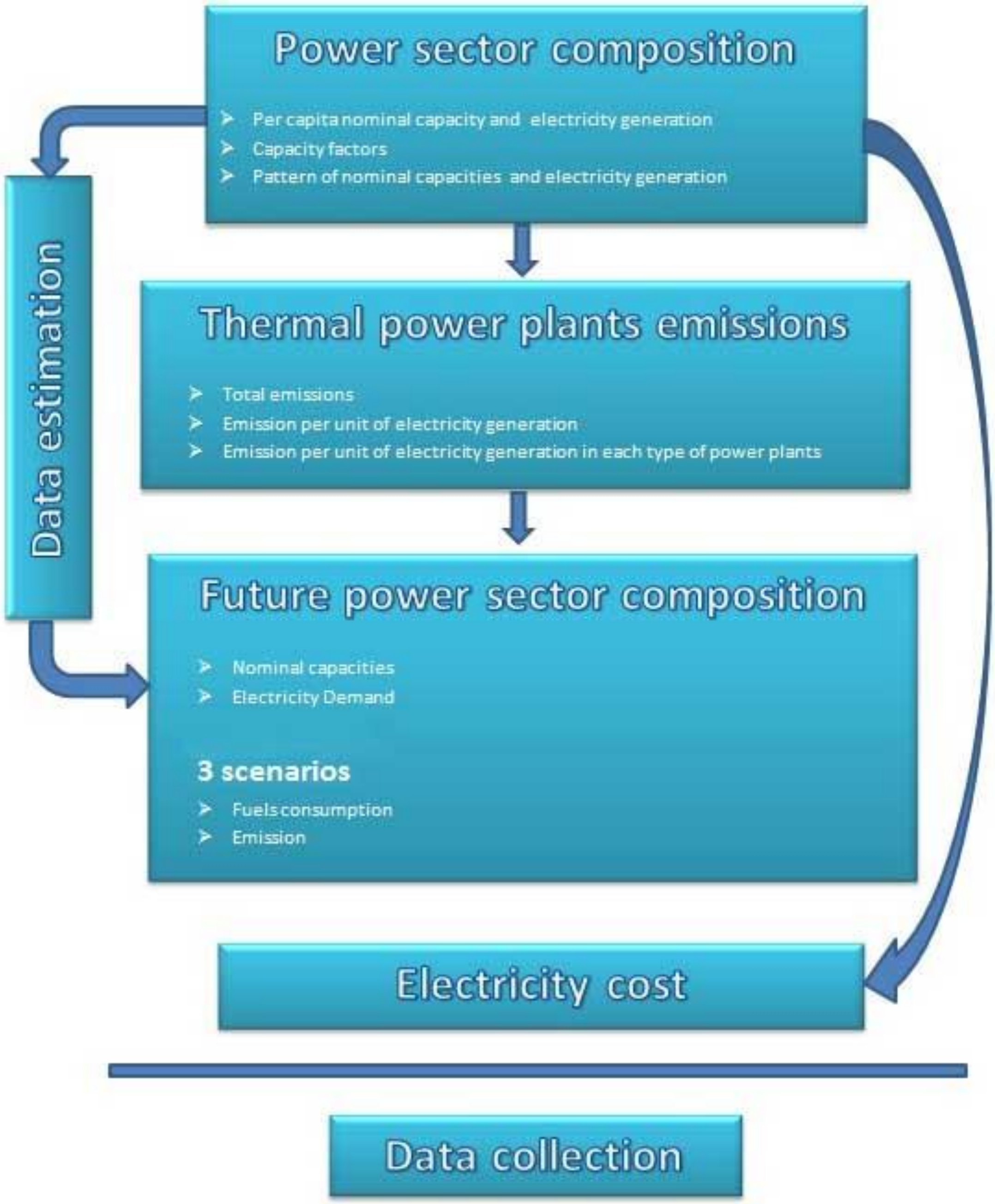


Figure 3-1. Flowchart summarizing the methodologies used in the research

3.2 Power sector composition

3.2.1 Method of data estimation

Some data are already available but others have to be estimated. There are several methods for estimating data; one that is widely used is polynomial curve fitting. This method tries to describe the relationship between a variable *X* as the function of available data and a response *Y* that seeks to find a smooth curve that best fits the data, but does not necessarily overtake through any data points. Mathematically, a polynomial equation of order *k* in *X* can be expressed in the following equation form (Klienbaum et al., 1998):

$$Y = C_0 + C_1X + C_2X^2 + ... + C_kX^k \qquad (3\text{-}1)$$

3.2.2 Per-capita nominal capacity

The per-capita nominal capacity (*PN*) for each year (*i*) is the total nominal capacity (*NC*) divided by the population (*P*) in that particular year. The per-capita nominal capacity in the year *i* can be calculated by the following equation:

$$PN_i = \frac{NC_i}{P_i} \times 10^6 \qquad (3\text{-}2)$$

3.2.3 Per-capita electricity consumption

The per-capita electricity consumption (*PC*) in the year *i* is the total electricity production (*EG*) minus electricity exchange with neighboring countries (*EX*), divided by the population in a particular year (P_i), which can be calculated by the following equation:

In this equation, electricity loss has not been taken into account.

$$PC_i = \frac{(EG_i - EX_i)}{P_i} \times 10^6 \qquad (3\text{-}3)$$

3.2.4 Percentage of nominal capacity and electricity generation

To understand the changes in pattern of nominal capacity and electricity generation, the share of each type of power plant (NP_i^n & PE_i^n) can be identified by the following equations:

$$NP_i^n = \frac{NC_i^n}{NC_i} \times 100 \tag{3-4}$$

$$PE_i^n = \frac{EG_i^n}{EG_i} \times 100 \tag{3-5}$$

3.3 Thermal power plant emissions

The methodology used to evaluate emissions in power plants is the one recommended by the Emissions Inventory Improvement Program of the U.S. Environmental Protection Agency. An emissions factor is a representative value that attempts to relate the quantity of a pollutant released into the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of the pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e.g., kilograms of particulate emitted per liter of diesel burned). In most cases, these factors are simply the averages of all available data of acceptable quality, and are generally assumed to be representative of the long-term averages for all the facilities in the source category (EIIP, 2001; U.S. Environmental Protection Agency, 2010).

The emissions factor of a fuel will be different based on the power plant type. As mentioned in Table 2.1, all thermal power plants (except diesel engines) use more than one type of fossil fuel. Therefore, the emissions factor for each fuel, such as diesel will be different from that of a steam turbine, gas turbine or diesel engine power plant. Consequently, fuel has three different combustion types and boiler configurations in these three types of power plant.

The amount of SO_2 is directly related to the amount of sulfur. The amounts of sulfur in diesel and fuel oil and the calorific value of natural gas have not been fixed so the mean value is used in the calculations.

3.3.1 Emissions production

To estimate the total emissions due to electricity generation in the country, the amount and type of fuel used in all power plants should be considered. The emission production is equal to the emissions factor (*EF*) multiplied by the amount of fuel consumed (*FC*). Therefore, the emissions *p* due to use of fuel *f* in power plant type *n* in the year *i*, can be calculated by the following equation:

$$EM_{i\ f}^{n\ p} = EF_{f}^{p\,n} \times FC_{i\,f}^{n} \qquad (3\text{-}6)$$

To assess the impact of each type of fuel in total emissions of each power plant, the contribution of each fuel in total emissions (*SF*) can be calculated by the following equation:

$$SF_{i\,f}^{n\,p} = \frac{EM_{i\ f}^{n\ p}}{\sum_{f} EM_{i\ f}^{n\ p}} \times 100 \qquad (3\text{-}7)$$

The annual emissions (EM_i^p) are the summation of emissions for all types of power plant due to all types of fuel used. This can be calculated by the following equation:

$$EM_i^p = \sum_n \sum_f EM_{i\,f}^{n\,p} \quad (3\text{-}8)$$

Thermal energy released due to inflammation of each type of fuel depends on the calorific value of the fuel (CV_f). The share of each type of fuel in total thermal energy consumed in power plants (PF) can be calculated by the following equation:

$$PF_{i\,f}^{n} = \frac{CV_f \times FC_{i\,f}^{n}}{\sum_f CV_f \times FC_{i\,f}^{n}} \times 100 \quad (3\text{-}9)$$

3.3.2 Emissions per unit of electricity generation

The emissions per unit of electricity generation (*EP*) in the Iranian power sector for each year is a function of total annual emissions (*EM*) divided by total electricity generated (*EG*) by the thermal power plants. This can be calculated by the following equation:

$$EP_i^p = \frac{EM_i^p}{EG_i^T} \quad (3\text{-}10)$$

3.3.3 Emissions per unit of electricity generation for each type of power plant

Awareness of the amount of emissions per unit of electricity generation in each type of thermal power plant is necessary for selecting the best of plant type with regard to air pollutants and for assessing possible emissions in the future. The emissions per unit of electricity generation for each type of power plant is a function of the emissions factor, fuel consumption in each type of power plant and electricity generation from that particular power plant. The emissions *p* per unit electricity generation in power plant type *n* in the year *i*, can be calculated by the following equation:

$$EP_{i}^{np} = \frac{\sum_{f} EF_{f}^{np} \times FC_{if}^{n}}{EG_{i}^{n}} \tag{3-11}$$

3.4 Prediction of future power plant sector composition

3.4.1 Scenarios

The scenarios are tools for ordering perceptions about alternative future environments. The results might not be an accurate picture of tomorrow, but may provide a better decision about the future. Regardless of how things could actually be, both the analysts and the decision makers will have a scenario that resembles a given future and will help researchers consider both the possibilities and consequences of the future (Schwartz, 1996). In addition, to understand the condition of fuel consumption and emissions in the future, three alternative scenarios will be discussed. These scenarios include two power plant compositions and a fuel type switching that is evaluated for the timeframe of 2025, which is the end of the Iran’s 20-year vision plan. The scenarios selected according to the thesis objectives. The first one is to verify the effect of the government future power sector composition. The second one selected to approximate the future condition if the composition does not change (business as usual). The third scenario is to verify the effect of applying a new energy policy in power plant fuel types on the future conditions.

Scenario 1

To estimate the future emissions, it is essential to know the power plant developmental pattern. The future power plant composition presented in Chapter 2-3 is considered as the first scenario. The first scenario mainly focuses on the new power plant composition that the government is planning to implement.

Scenario 2 (old composition)

In this scenario, the fuel types and the composition of power plants in the future are assumed to be the same as in year 2009. No improvement in technology, change in the power plant composition and fuel consumption or apply in long-term policies has been considered. In other words, this is the simplest way to simulate the emissions and fuel consumption in the future.

Scenario 3 (fuel switching)

The difference between the first two scenarios is the composition of power plants. While in this scenario, the main point is the fuel switching, while the power plant composition will remain the same as the first scenario. As some countries are seeking to reduce their emissions by converting to a low carbon content type of fuel, the effect of a stable supply of natural gas and reduction in the use of liquid fuels in thermal power plants is investigated in this scenario. Supplying 100% energy from natural gas and eliminating diesel are considered for gas turbines and combined cycle power plants. For steam turbine power plants, diesel is used at the starting stage. For this reason, using natural gas instead of only fuel oil has been evaluated.

3.4.2 Total capacity prediction

There are several methods for predicting electricity demands in the future, which are affected by various factors. These factors are the energy prices, per-capita gross domestic product (GDP), population, weather, customer income, etc. (Bianco et al., 2009). However, these factors are not taken into account in this study and the trend of total power capacity is considered to predict the future. The method used to estimate long-term time series forecasting is polynomial curve fitting, which is described in section 3.1.1 Eq. (3-1). The reason for selection of this method is to show that if there was no change in energy policy of the country what would be the electricity demand in the future. The policies such as power plant composition, energy conservation and energy price control mechanisms.

3.4.3 Power plants nominal capacities

The nominal capacity (*NC*) in power plant type *n* can be calculated by the following equation:

$$NC^n = \frac{NP^n \times NC}{100} \tag{3-12}$$

For the second scenario, the share of nominal capacities is considered as being the same as 2009. In this scenario, the nominal capacity for each type of power plant can be calculated by multiplying its share with the total nominal capacity of the country in that particular year. For the first and third scenarios, the nominal capacities or their shares in 2025 have already been presented and described in Section 2.3. For 2010 to 2024 since the date of launching new power plants is not specified, linear prediction will be applied for estimation.

3.4.4 Capacity factor

The power plant capacity factor (*CF*) is the ratio of the electricity generated by power plant over a period of time (e.g. one-year equivalent to 8766 hours), and its generation operated at full nominal capacity for the entire time. In this study, it is necessary to calculate this value to estimate the future electricity generation by thermal power plants. The average value of capacity factors in the last years will be considered for its value in the future. The trend of change in capacity factors of each thermal plant type in the past years can be calculated by the following equation:

$$CF_i^n = \frac{EG_i^n}{NC_i^n \times 8.766} \times 100 \qquad (3\text{-}13)$$

3.4.5 Electricity generation

The future electricity generation by power plants (*EG*) can be calculated using the following equation:

$$EG_i^n = \frac{CF^n \times NC_i^n \times 8.766}{100} \qquad (3\text{-}14)$$

3.4.6 Fuel consumption per unit of electricity generated

The fuel *f* consumption per unit electricity generation in power plant type *n* in the year *i* can be calculated by the following equation:

$$FE_{i\,f}^{\,n} = \frac{FC_{i\,f}^{\,n}}{EG_i^n} \tag{3-15}$$

To estimate the average fuel consumption for a unit of electricity production in each type of power plant, only the values related to certain years are applied. The average fuel consumption for certain years is considered as a selected value, calculated by the following equation:

$$FE_f^n = \frac{FE_{f\ 2001}^n + FE_{f\ 2002}^n + ... + FE_{f\ 2008}^n}{8} \tag{3-16}$$

3.4.7 Fuel consumption in the future

The total fuel consumption in thermal power plants (*FC*) in the future is estimated by multiplying the average fuel consumption (*FE*) per unit of electricity generated by power plants in last years and the electricity generated (*EG*) which predicted for the future. This can be calculated by the following equation:

$$FC_{i\,f}^{\,n} = FE_f^n \times EG_i^n \tag{3-17}$$

3.4.8 Fuel consumption in fuel switching scenario

In the third scenario due to the replacement of fuel oil with natural gas, the consumption of fuel oil in power plants is eliminated. The diesel consumption used in diesel engines or as the starter in steam turbines can still be calculated by Eq. (3-17). In fact, natural gas fuel (*ng*) should compensate for the thermal energy of liquid fuels; its excess volume use can be calculated by the following equation:

$$FC_{ng}^{n} = \frac{CV_{sf}}{CV_{ng}} \times FC_{sf}^{n} \tag{3-18}$$

The substituted fuel (*sf*) for the gas turbine and combined cycle is diesel and for the steam turbine it is fuel oil. The natural gas caloric value depends on the source of fuel. However in this study the average value has been considered in the calculation.

3.4.9 Emissions in the future

The pollutant *p* emissions per unit electricity generation for power plant type *n* is calculated by multiplying the emissions factor (*EF*) and average fuel consumption per unit of electricity generation (*FE*) in the respective power plants in the last years, which can be calculated by the following equation:

$$EP^{np} = EF_{f}^{np} \times FE_{f}^{n} \tag{3-19}$$

The total of annual emissions (*EM*) is equal to the summation of emissions per unit of electricity generation (*EP*) multiplied by the amount of electricity generated (*EG*) by the respective power plant (*n*) in the year (*i*). This can be calculated by the following equation:

$$EM_i^p = \sum_n EP^{n\,p} \times EG_i^n \tag{3-20}$$

For the fuel-switching scenario, emissions (*EM*) can be calculated by multiplying the emissions factor (*EF*) by the amount of fuel consumed (*FC*). Therefore, the total emissions *p* of fuel *f* in power plant type *n*, can be calculated by the following equation:

$$EM^p = \sum_n \sum_f EF_f^{p\,n} \times FC_f^n \tag{3-21}$$

3.5 Electricity cost

Levelized electricity cost (LEC) is the price at which electricity must be generated from a specific source in order to break even (International Energy Agency, 2005). It is an economic assessment of all the electricity generated by a technology as well as the cost of the power generation system, including the building and operating costs over its lifetime. The levelized cost is useful in evaluating the financial feasibility of a power generation technology and the cost of one technology against other alternatives. In other words, it is the methodology used to compare different technologies in the electricity market. The LEC can be calculated by the following equation, which *OMC* is operation and maintenance cost, *FC* is fuel cost, *r* is interest rate, *n* is total life time of the power plant and *i* is the year.

$$\mathrm{LEC}=\frac{\sum_{i=1}^{n}\frac{I_i+\mathrm{OMC_i}+\mathrm{FC_i}}{(1+r)^i}}{\sum_{i=1}^{n}\frac{E_t}{(1+r)^i}} \tag{3-22}$$

In this study, to approximate the relative cost of electricity generated in each alternative electricity generator, the simple levelized electricity cost (sLEC) is selected as a methodology. The main reason to select this methodology is the limitation of gathering accurate an up-to-date information about many minor costs related to the electricity generation in the country. More accurate analyses need accurate data and taking into account the effect of many factors such as fuel price in local and international market and also considering the variation of inflation as well. In this methodology, the common and major costs of power generation, including capital, operation and maintenance, and fuel have been considered based on their performances in Iran. The sLEC can be calculated using the following equation:

$$\mathrm{sLEC}=\frac{\mathrm{OCC}\times\mathrm{CRF}+\mathrm{OMC}}{87.66\times\mathrm{CF}}+\mathrm{FT}\times\mathrm{HR} \tag{3-23}$$

In this equation, *OMC* is fixed and the variable operation and maintenance costs. *FT* is fuel cost in terms of thermal value, and *HR* is the heat rate, the ratio of input energy and output electricity generated, which depends on the efficiency of the power plant. *CF* is capacity factors, the ratio of the electricity generated by power plant over a period of time (e.g., one-year equivalent to 8,766 hours), and its generation operated at full nominal capacity for the entire time. *OCC* is the overnight capital cost the cost of a project if it was completed "overnight" and also if no interest was considered during construction. *CRF* is the capital recovery factor, which indeed simulates the overnight capital cost as a constant annuity cost for a given length of time or number of annuities received (*t*). The *CRF* can be calculated by the following equation:

$$CRF = \frac{r(1+r)^t}{(1+r)^t - 1} \qquad (3\text{-}24)$$

To evaluate the impact of carbon emissions trading on electricity cost, the effects of carbon price variation on the electricity cost (*CEC*) will be calculated by multiplying the emissions per unit electricity generation (*EP*) in Iranian thermal power plants with carbon prices (*CP*). This can be calculated by the following equation:

$$CEC^n = EP^n \times CP \qquad (3\text{-}25)$$

3.6 Data collection

3.6.1 Power sector data

The data used for this study are based on the electricity generation, exchanged electricity with neighboring countries, fossil fuel used and population of Iran from 1967 to 2009. These data were collected from references (Ministry of Energy, 1979 - 2007; Statistical Centre of Iran, 2006; TAVANIR, 2008) and are presented in Appendix A in Table A - 1 to Table A - 7.

The emission factors for all types of fuel with different combustion types were mostly obtained from references (EPA, 2002; U.S. Environmental Protection Agency, 2010) and given in Table 3.1.

Table 3.1. Emission factors used for estimating emission in thermal power plants

Fuel type	Power plant type	Emission type				Unit
		CO_2	* SO_2	NO_x	CO	
Natural gas	Steam turbine	1.86	9.32×10^{-6}	4.35×10^{-3}	1.31×10^{-3}	$\frac{kg}{m^3}$
	Gas turbine or combined cycle	1.74	0.0149S	5.07×10^{-3}	1.30×10^{-3}	$\frac{kg}{m^3}$
Fuel oil	Steam turbine	2.93	0.0188S	5.64×10^{-3}	6.00×10^{-4}	kg/l
Diesel	Steam turbine	2.68	0.0188S	3.84×10^{-3}	6.00×10^{-4}	kg/l
	Gas turbine or combined cycle	2.61	0.0168S	1.46×10^{-2}	5.48×10^{-5}	kg/l
	Diesel engine	2.73	4.82×10^{-3}	7.33×10^{-2}	1.58×10^{-2}	kg/l

* S% indicates percentage of Sulfur in the respective fuel, by weight

Source: EPA, 2002; U.S. Environmental Protection Agency, 2010

The characteristics of fuels used in power plants are important to assess the contribution of each fuel to the emissions. The SO_2 emission factor can be calculated by multiplying the weight percent sulfur in the fuel by the numerical value preceding sulfur (*S*). The fuel oil and diesel produced by the local refineries are high in sulfur content about 2.5-3.5 wt% (Ghiaseddin et al., 2001) and 500-10,000 *ppm* (Research Institute of Petroleum Industry, 2008). The sulfur content in natural gas is assumed to be 0.00057% (2,000 $grains/10^6 scf$) and natural gas density 0.8 kg/m^3 (0.05 lb/ft^3) (U.S. Environmental Protection Agency, 2010). In the coal-fired power plant, the emissions per unit of electricity generation is collected from (Mahlia, 2002) and shown in Table 3.2 where the coal consumption per unit electricity generation in coal-fired power plants is assumed to be 380 tons/GWh based on (Steenhof et al., 2007). Calorific values are essential in calculating natural gas consumption in fuel switching scenario. These values are 9790 kcal/l for fuel oil, 9232 kcal/l for diesel and between 8.509 and 9.099 kcal/l for natural gas (TAVANIR, 2010).

Table 3.2. Emissions per unit of electricity generation in coal-fired power plants

SO_2 (*kg/GWh*)	CO_2 (*kg/GWh*)	NO_x (*kg/GWh*)	CO (*kg/GWh*)
13,900	1,180,000	5,200	200

3.6.2 Financial data

The majority of data needed for electricity cost calculation are not constant values because of various uncertainties including technology, policy and international affairs. Therefore, the minimum and maximum values for each cost type were gathered for analysis. There is less uncertainty about fuel cost in the country and high uncertainty about capital cost for power plants, which will depend on foreign technology. Natural gas selected as the fossil fuel type in the analyses, because it is the major type of fossil fuel with about 75%, which this share continuously increased in last decades. Natural gas is the local production, and has a light dependency on international price mechanism. Consequently, its price, which is supposed to be used in most thermal power plants is considered to be 1-2 $/MMBtu. Although this price is less than the normal price in the international market, it has been considered in the calculation because fuel price crucially depend on location and also because of the exclusion of transportation and reduced potential for the export of natural gas by pipeline (PNG) or as Liquefied Natural Gas (LNG) in the near future (Ardekani et al., 2007; Gharib et al., 2011; Najibi et al., 2009b). Three carbon prices are assumed $10, $20 and $30 for each metric ton of carbon dioxide (CO_2). There where high variation of inflation rates in the country in last ten years, so the average value (14.5%) have been considered as the inflation (International Monetary Fund, 2012). The interest rate which must be a little more than inflation, have been considered 15% in the calculations. There were some limitations in collecting data because of the lack of official data in Iran. For example, the budget of the NPP and the related nuclear fuel cycle as well as the real maintenance costs for the thermal power plants in Iran cannot be determined exactly. In these cases, international data have been used instead of local data. The data related to the financial information of power plants was gathered from Refs (Massachusetts Institute of Technology, 2009; Najibi et al., 2009a; National renewable energy laboratory, 2010) and shown in Table 3.3.

Table 3.3. Power plants financial and technical information

Power plant type		Overnight cost ($/kW)	Fix OMC ($/kW-Y)	Variable OMC ($/MWh)	Capacity factor	Fuel cost ($/MMBtu)	Heat rate (Btu/kWh)	Life time (Year)
Steam turbine	Min	650	6	3	0.64	1	9,626	30
	Max	1,500	25	26	0.71	2	9,626	
Gas turbine	Min	650	6	3	0.26	1	11,628	20
	Max	1,500	25	26	0.35	2	11,628	
Combined cycle	Min	554	5	1	0.50	1	8,029	20
	Max	1,172	17	3	0.61	2	8,029	
Coal-fired	Min	1,549	19	2	0.85	2.6	8,870	30
	Max	5,350	37	9	0.85	2.6	8,870	
Nuclear	Min	3,206	12	0	0.9	0.67	10,400	40
	Max	7,550	90	10	0.86	0.67	10,400	
Hydro power	Min	1,239	14	2	0.07	-	-	40
	Max	3,226	15	5	0.32	-	-	
Wind turbine	Min	1,206	12	0	0.21	-	-	30
	Max	2,341	49	6	0.35	-	-	
Geothermal	Min	1,664	66	0	0.95	-	-	40
	Max	3,901	160	28	0.7	-	-	
Photovoltaic	Min	5,058	7	0	0.26	-	-	30
	Max	6,000	34	0	0.1	-	-	
Solar thermal	Min	3,623	54	0	0.5	-	-	30
	Max	5,899	66	0	0.24	-	-	

Chapter 4 **:**

Results

4.1 Iranian power sector composition

4.1.1 Power generation growth

The nominal capacity and electricity production growth by type of power plant in Iran is shown in Figure 4-1 and Figure 4-2.

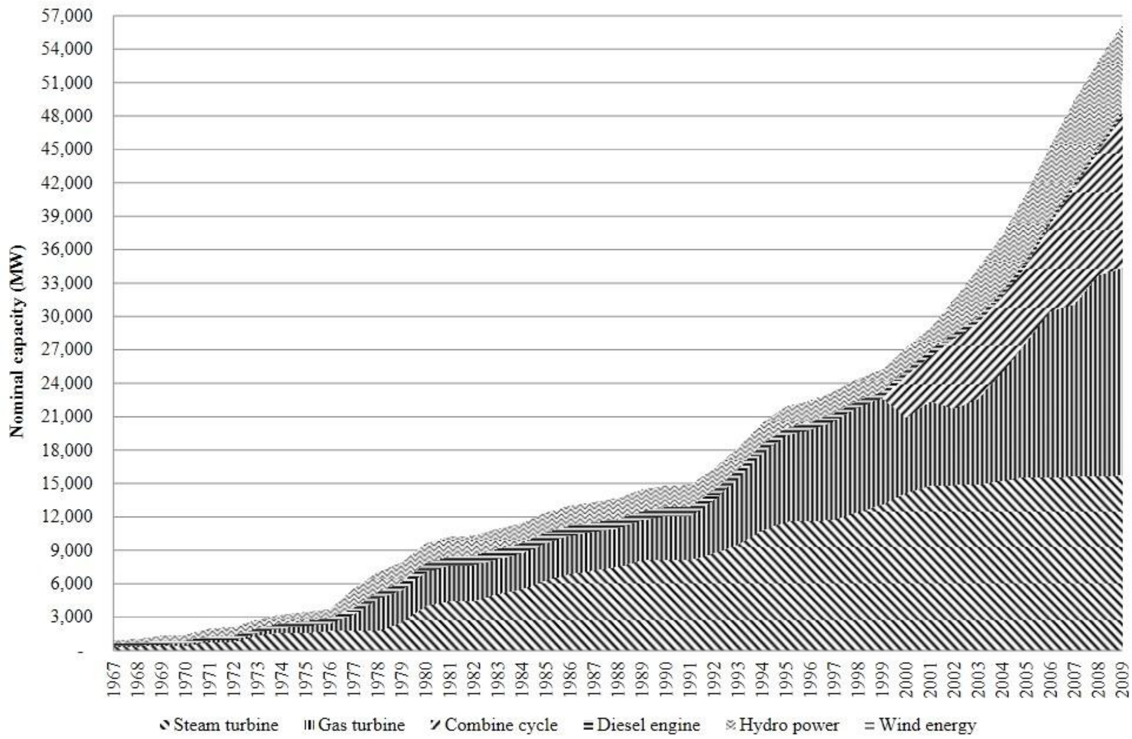


Figure 4-1. Nominal capacity (MW) of Iranian power plants by type from 1967 to 2009

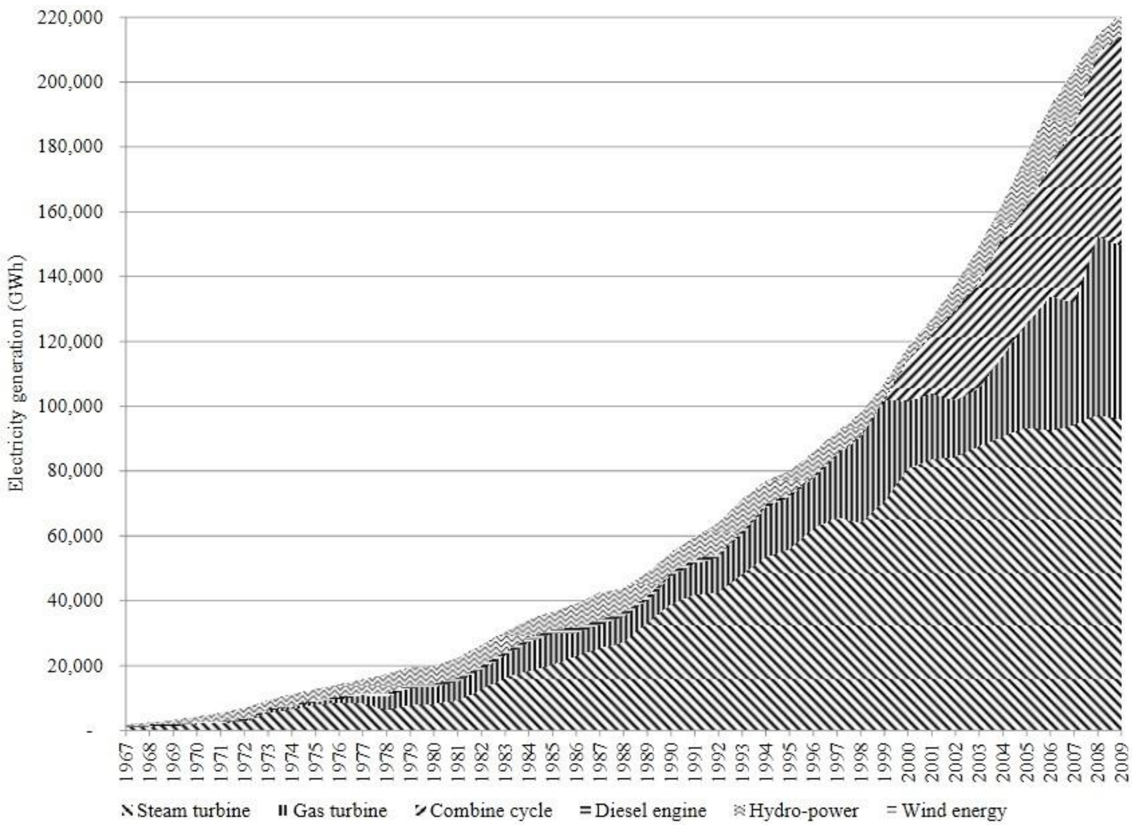


Figure 4-2. Electricity generation (GWh) in Iranian power plants by type from 1967 to 2009

4.1.2 Per-capita capacities

There is empirical evidence of a long-run relationship between per-capita electricity generation and real per-capita GDP in Iran (Squalli, 2007). The annual population growth is estimated using the data in Table A - 4 and Eq. (3-1). The nominal capacity and electricity consumption per person have been calculated using Eqs. (3-2) and (3-3) based on the data in Table A - 1 to Table A - 4. The share of exchange electricity with neighboring countries is very small (~1%); therefore, the per-capita rate of electricity generation and consumption should remain the same. The results are tabulated in Table 4.1 and illustrated in Figure 4-3.

Table 4.1. Per-capita nominal capacity and per-capita electricity consumption in Iran

Year	Per-capita nominal capacity (W)	Per-capita electricity consumption (kWh)
1967	36	71
1968	39	93
1969	49	120
1970	51	156
1971	71	196
1972	72	237
1973	93	311
1974	103	358
1975	106	394
1976	109	421
1977	158	448
1978	192	474
1979	207	509
1980	242	500
1981	247	542
1982	240	613
1983	245	685
1984	247	738
1985	259	769
1986	264	792
1987	262	838
1988	262	839
1989	270	910
1990	270	1,001
1991	265	1,066
1992	286	1,121
1993	314	1,226
1994	347	1,307
1995	368	1,343
1996	373	1,423
1997	381	1,503
1998	393	1,568
1999	399	1,685
2000	423	1,834
2001	443	1,943
2002	475	2,081
2003	510	2,232
2004	546	2,388
2005	591	2,556
2006	642	2,728
2007	691	2,842
2008	729	2,952

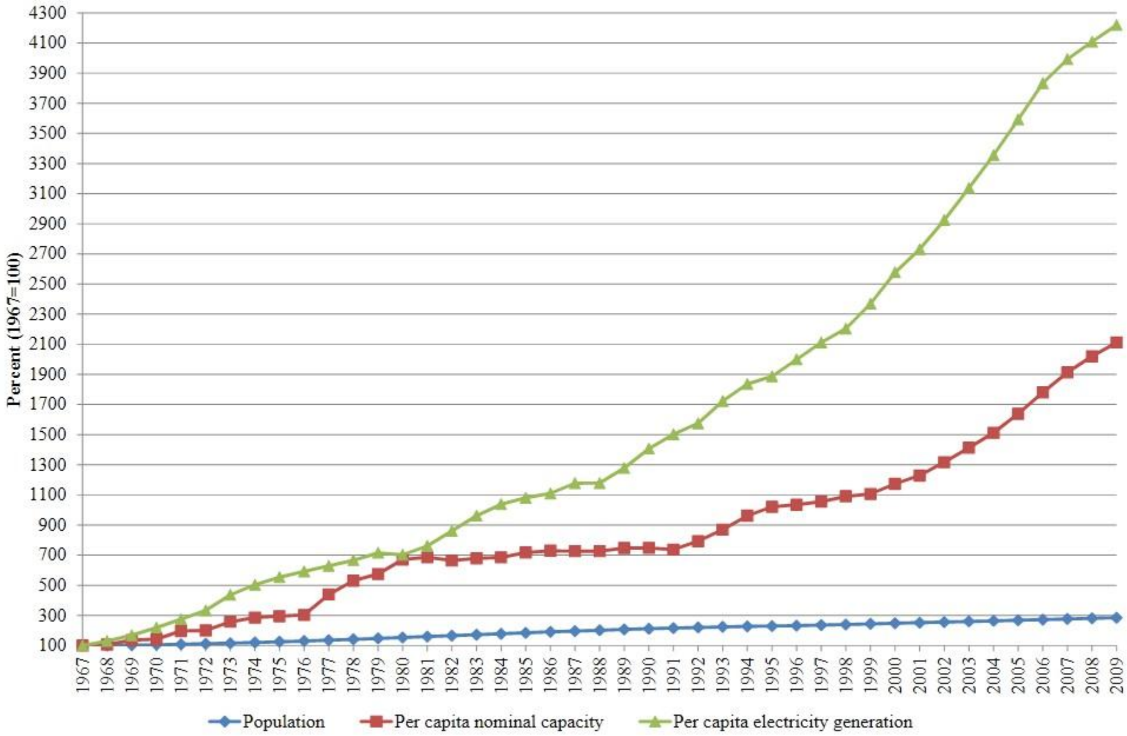


Figure 4-3. The growth of per-capita nominal capacity and per-capita electricity consumption and population between 1967 and 2009

4.1.3 Pattern of electricity generation

The pattern of electricity generation and nominal capacity, based on the power plant type is calculated based on the data in Table A - 1 and Table A - 2 and Equations (3-4) and (3-5). The results are tabulated in Table 4.2, Table 4.3 and illustrated in Figure 4-4 and Figure 4-5.

Table 4.2. Power plants electricity generation contribution (%) from 1967 to 2009

Year	Steam turbine	Gas turbine & combined cycle	Diesel engine	Hydro power	Wind energy
1967	39.7	3.0	21.5	35.7	0
1968	44.8	3.2	16.9	35.2	0
1969	41.8	2.7	13.8	41.8	0
1970	46.5	3.6	10.6	39.3	0
1971	38.2	3.5	9.5	48.8	0
1972	36.6	3.9	8.2	51.4	0
1973	57.6	5.8	6.1	30.5	0
1974	58.6	6.2	4.6	30.6	0
1975	60.9	7.5	4.6	27.0	0
1976	59.5	7.9	4.6	28.0	0
1977	52.1	16.2	5.0	26.7	0
1978	36.3	22.6	5.1	35.9	0
1979	40.0	27.4	4.8	27.9	0
1980	41.2	25.6	4.9	28.3	0
1981	40.9	26.3	5.0	27.8	0
1982	47.7	23.3	4.5	24.5	0
1983	53.4	22.4	3.9	20.3	0
1984	53.7	25.8	3.7	16.9	0
1985	55.0	26.1	3.8	15.1	0
1986	58.5	18.3	3.9	19.3	0
1987	59.6	17.2	3.5	19.7	0
1988	61.6	18.6	3.1	16.7	0
1989	67.8	14.3	2.4	15.4	0
1990	70.7	15.9	2.3	11.1	0
1991	70.3	15.8	2.1	11.8	0

Table 4-2, continued. Power plants electricity generation contribution (%) from 1967 to 2009

Year	Steam turbine	* Gas turbine	Combined cycle	Diesel engine	Hydro power	Wind energy
1992	66.2	17.0		1.9	14.9	0
1993	67.5	17.4		1.3	13.8	0
1994	69.2	20.0		1.1	9.7	0
1995	69.8	20.2		0.9	9.1	0
1996	72.7	18.0		0.7	8.6	0
1997	71.1	20.9		0.5	7.5	0
1998	65.4	27.1		0.4	7.2	0
1999	65.9	29.1		0.4	4.6	0
2000	68.1	17.6	10.9	0.3	3.1	0
2001	65.7	16.0	14.1	0.3	4.0	0
2002	61.1	12.7	20.0	0.3	5.8	0
2003	58.6	11.8	22.0	0.2	7.4	0
2004	55.7	15.3	22.3	0.2	6.5	0
2005	52.4	18.0	20.3	0.1	9.0	0
2006	48.0	21.4	21.0	0.1	9.4	0
2007	46.2	18.4	26.4	0.1	8.8	0.1
2008	45.3	25.6	26.6	0.1	2.3	0.1
2009	43.3	24.3	29.0	0.1	3.3	0.1

* Since 2000 data of gas turbine and combined cycle types have been separated.

Table 4.3. Power plants nominal capacity contribution (%) from 1967 to 2009

Year	Steam turbine	Gas turbine & combined cycle	Diesel engine	Hydro power	Wind energy
1967	36.7	9.0	21.2	33.1	0
1968	34.8	9.7	24.8	30.7	0
1969	33.3	9.7	21.8	35.2	0
1970	31.1	9.7	22.2	37.0	0
1971	37.4	6.8	15.8	40.1	0
1972	35.6	8.2	17.8	38.4	0
1973	48.6	8.6	14.0	28.8	0
1974	49.4	12.8	12.9	25.0	0
1975	45.7	17.7	13.3	23.3	0
1976	46.7	17.8	13.7	21.8	0
1977	30.9	27.1	9.7	32.4	0
1978	24.5	41.1	8.7	25.7	0
1979	31.3	37.1	8.9	22.8	0
1980	41.4	31.8	8.1	18.7	0
1981	43.2	31.0	8.1	17.6	0
1982	42.9	31.1	8.5	17.5	0
1983	46.2	28.8	8.5	16.5	0
1984	47.7	28.6	7.9	15.8	0
1985	50.8	26.8	7.9	14.6	0
1986	52.7	26.4	6.8	14.0	0
1987	53.8	26.2	6.3	13.7	0
1988	54.6	25.5	5.9	14.0	0
1989	56.0	24.9	5.6	13.5	0
1990	54.6	26.6	5.6	13.2	0
1991	54.5	26.5	5.9	13.2	0
1992	53.4	29.4	5.2	12.0	0
1993	52.2	32.6	4.5	10.7	0
1994	52.6	34.1	3.7	9.6	0

Table 4-3, continued. Power plants nominal capacity contribution (%) from 1967 to 2009

Year	Steam turbine	* Gas turbine	Combined cycle	Diesel engine	Hydro power	Wind energy
1995	52.7		35.3	3.0	8.9	0
1996	51.8		36.4	3.0	8.8	0
1997	50.2		38.3	2.9	8.6	0
1998	50.7		38.6	2.5	8.2	0
1999	52.0		37.8	2.3	7.9	0
2000	52.0	24.9	13.8	2.0	7.4	0
2001	51.1	26.1	14.0	1.8	6.9	0
2002	47.1	21.8	20.0	1.6	9.6	0
2003	43.4	22.3	19.9	1.4	12.9	0
2004	40.8	26.0	18.3	1.3	13.4	0.1
2005	38.0	29.4	16.7	1.2	14.7	0.1
2006	34.3	32.8	17.3	0.9	14.5	0.1
2007	31.6	31.2	21.2	0.8	15.0	0.1
2008	29.5	34.1	21	0.8	14.5	0.1
2009	28.0	33.1	24.3	0.8	13.7	0.2

* Since 2000 data of gas turbine and combined cycle types have been separated.

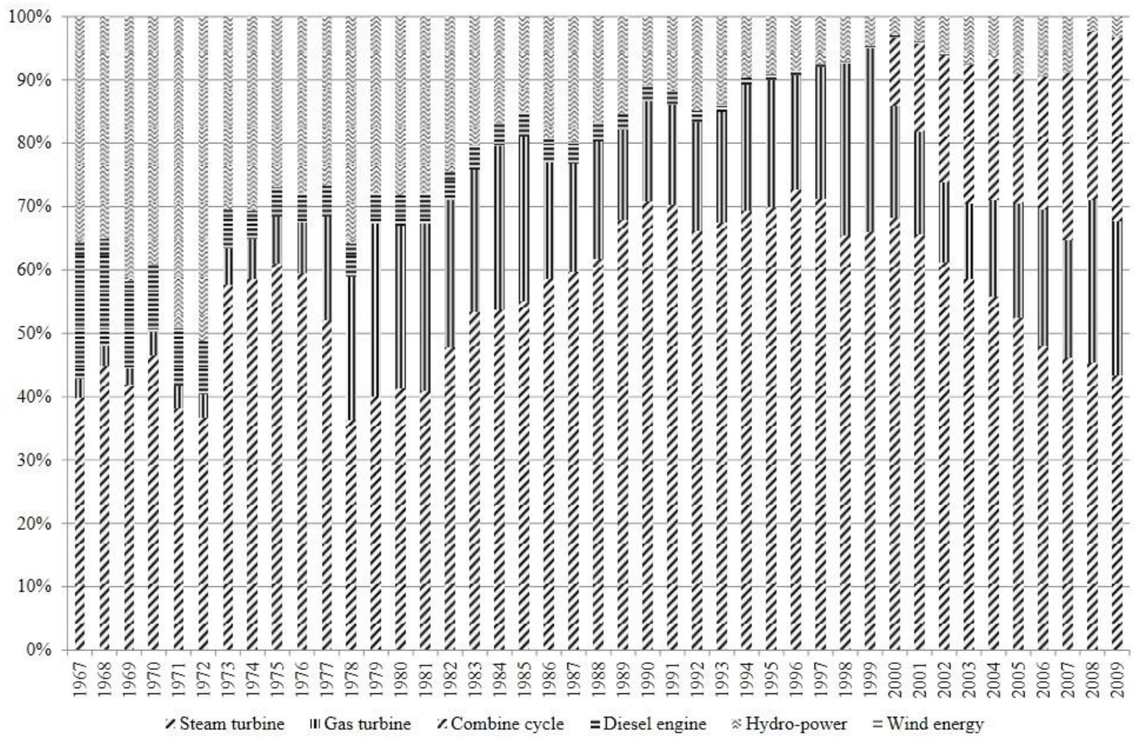


Figure 4-4. Pattern of electricity generation for each type of power plants from 1967 to 2009

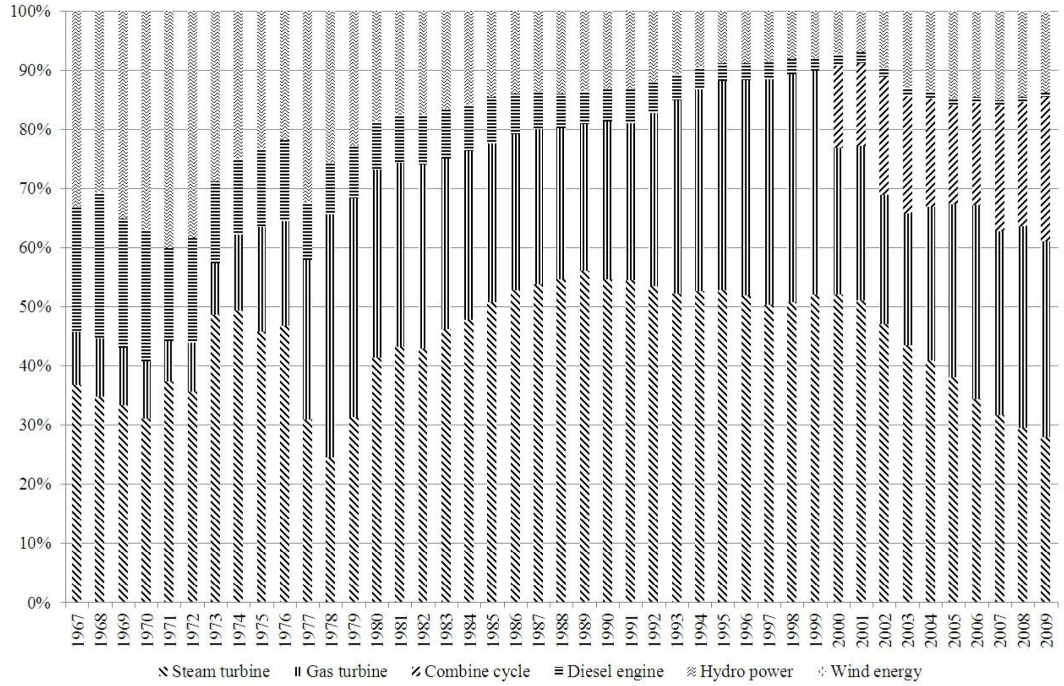


Figure 4-5. Pattern of nominal capacity for each type of power plants in Iran from 1967 to 2009

The share of each type of power plant in nominal capacity and electricity generation in 2009 is tabulated in Table 4.4 and is shown in Figure 4-6.

Table 4.4. Electricity generation and nominal capacity share by power plant in 2009

	Steam turbine (%)	Gas turbine (%)	Combined cycle (%)	Diesel engine (%)	Hydro power (%)	Wind energy (%)
Nominal capacity	28.0	33.1	24.3	0.8	13.7	0.2
Electricity generation	43.3	24.3	29.0	0.1	3.3	0.1

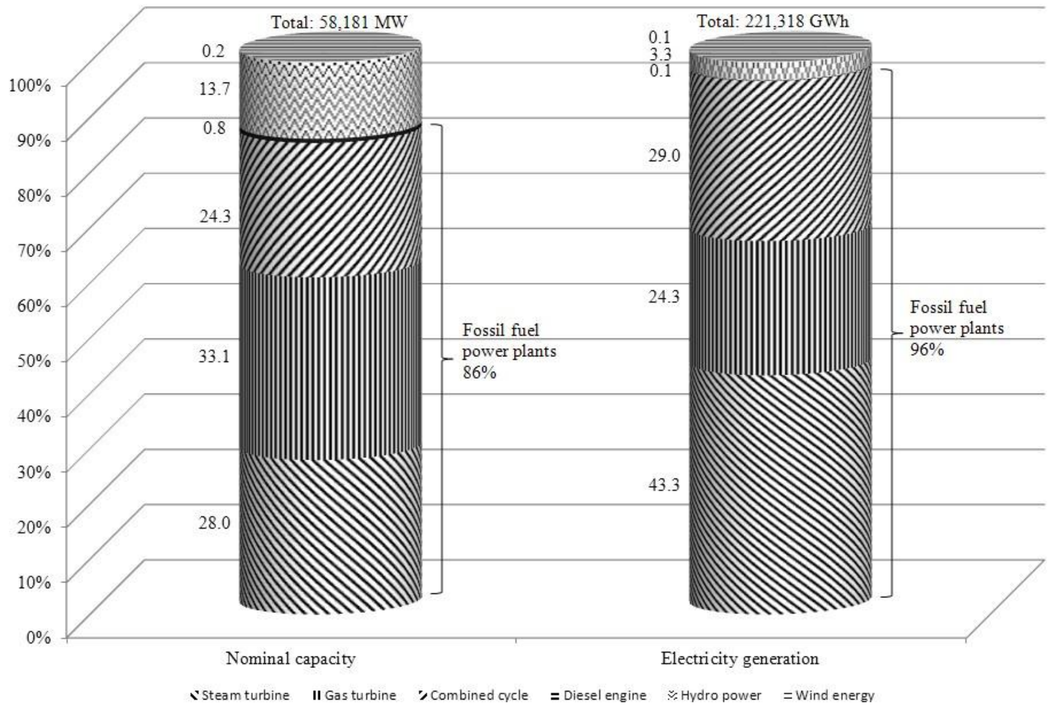


Figure 4-6. Share of nominal capacity and electricity generation in Iranian power plants in 2009

4.1.4 Capacity factors

The trends of capacity factors in the past nine years were calculated using Eq. (3-13) and data in Table A - 1 and Table A - 2. The results are compiled in Table 4.5 and are shown in Figure 4-7.

Table 4.5. Capacity factor in Iranian power plants from 2001 to 2009

Year	Steam turbine (%)	Gas turbine (%)	Combined cycle (%)	Diesel engine (%)	Hydro (%)
2001	64.47	30.68	50.29	7.02	28.86
2002	64.77	29.17	50.03	8.28	30.33
2003	67.10	26.34	54.93	6.72	28.63
2004	67.95	29.35	60.53	5.83	24.19
2005	68.39	30.42	60.43	4.91	30.36
2006	67.83	31.65	58.73	6.00	31.54
2007	68.91	27.80	58.56	6.14	27.65
2008	71.09	34.65	58.51	5.57	7.44
2009	69.57	33.04	53.55	3.33	10.67

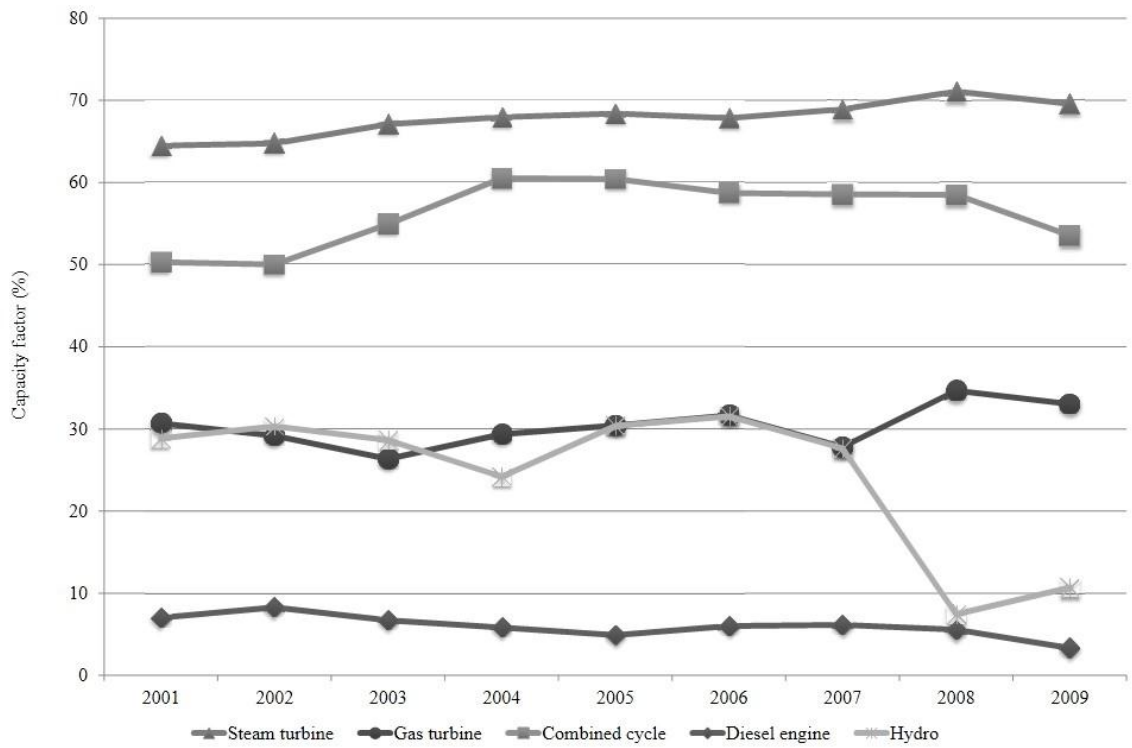


Figure 4-7. Iranian power plants capacity factor from 2001 to 2009

4.1.5 Fuel consumption per unit electricity generation

The average fuel consumption per unit electricity generation for each type of thermal power plant from 2001 to 2009 is calculated using equations (3-15) and (3-16) and data from Table A - 2 and Table A - 7. The results are tabulated in Table 4.6.

Table 4.6. Average fuel consumption per unit of electricity generation in Iranian thermal power plants

Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine
Natural gas (m^3/kWh)	0.1841	0.2910	0.2019	-
Diesel (l/kWh)	0.0008	0.0602	0.0220	0.2981
Fuel oil (l/kWh)	0.0785	-	-	-

4.2 Emissions production

Based on Table A - 5 to Table A - 7, the quantity of all types of fuel consumed in power plants in Iran is illustrated in Figure 4-8.

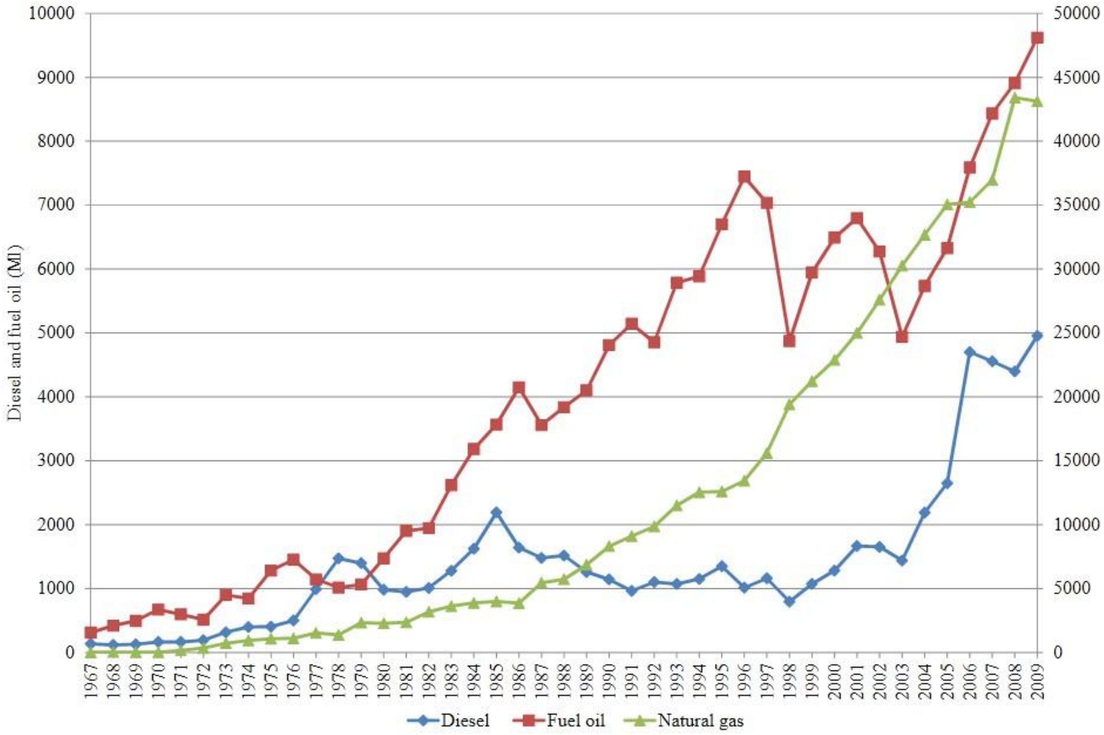


Figure 4-8. Total fuel consumed in Iranian power plants from 1967 to 2009

Figure 4-9 also shows the share of total energy for each fuel type used in Iranian thermal power plants.

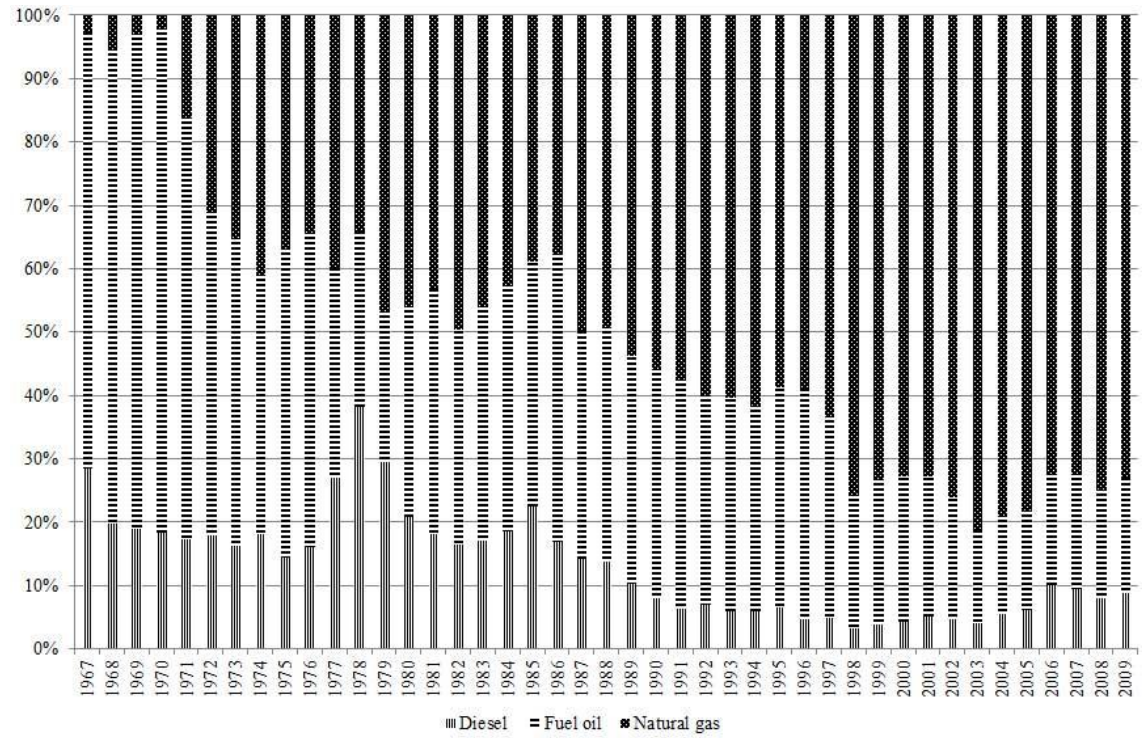


Figure 4-9 Share of each fuel type in total energy consumed in thermal power plants

The total emissions in Iran's power plants were calculated based on equations (3-6) and (3-8) and Table A - 5 to Table A - 7 and Table 3.1. For the years between 1967 and 1979 (Table A - 5), only the total fuel consumed was presented. To estimate the fuel consumption for each type of power plant for these years, the total diesel oil is divided by 27% in diesel engines, 70% in both gas turbine and combined cycle and 3% in steam turbines. The total natural gas consumed, is divided by 45% in steam turbines and 55% in gas turbines. The total emissions in Iranian thermal power plants from 1967 to 2009 are presented in Table 4.7 and illustrated in Figure 4-10.

Based on Table 2.1, most of the thermal power plants used both liquid fuel and natural gas. The share of each type of fuel in total thermal energy consumed, and total emissions in 2009 are calculated by using Eqs. (3-7) and (3-9), and presented in Table 4.8.

Table 4.7. Total emission (kton) in Iranian power plants from 1967 to 2009

Year	CO_2	SO_2	NO_x	CO
1967	1,294	19	6	1
1968	1,602	25	6	1
1969	1,829	29	7	1
1970	2,445	39	9	1
1971	2,481	35	9	1
1972	2,634	30	10	2
1973	4,769	53	18	3
1974	5,227	51	21	3
1975	6,762	76	25	4
1976	7,585	86	29	4
1977	8,723	72	44	7
1978	9,342	69	57	9
1979	10,988	71	53	8
1980	10,974	91	50	9
1981	12,263	114	55	9
1982	14,068	117	61	11
1983	17,568	158	71	12
1984	20,568	192	82	13
1985	23,382	219	95	14
1986	23,442	247	90	14
1987	24,217	212	92	16
1988	25,623	228	92	16
1989	27,850	241	92	17
1990	32,245	280	103	19
1991	34,172	297	106	21
1992	35,049	282	110	21
1993	40,631	335	117	23
1994	43,039	341	123	24
1995	46,036	389	128	24
1996	48,913	428	129	25
1997	52,006	407	137	27
1998	51,528	281	135	30
1999	58,662	344	156	34
2000	63,838	377	167	36
2001	69,598	398	184	38
2002	72,650	368	194	42
2003	73,050	291	194	44
2004	81,574	343	221	47
2005	88,661	380	242	51
2006	97,817	470	281	52
2007	102,903	516	292	55
2008	115,150	542	325	63
2009	118,079	582	336	63

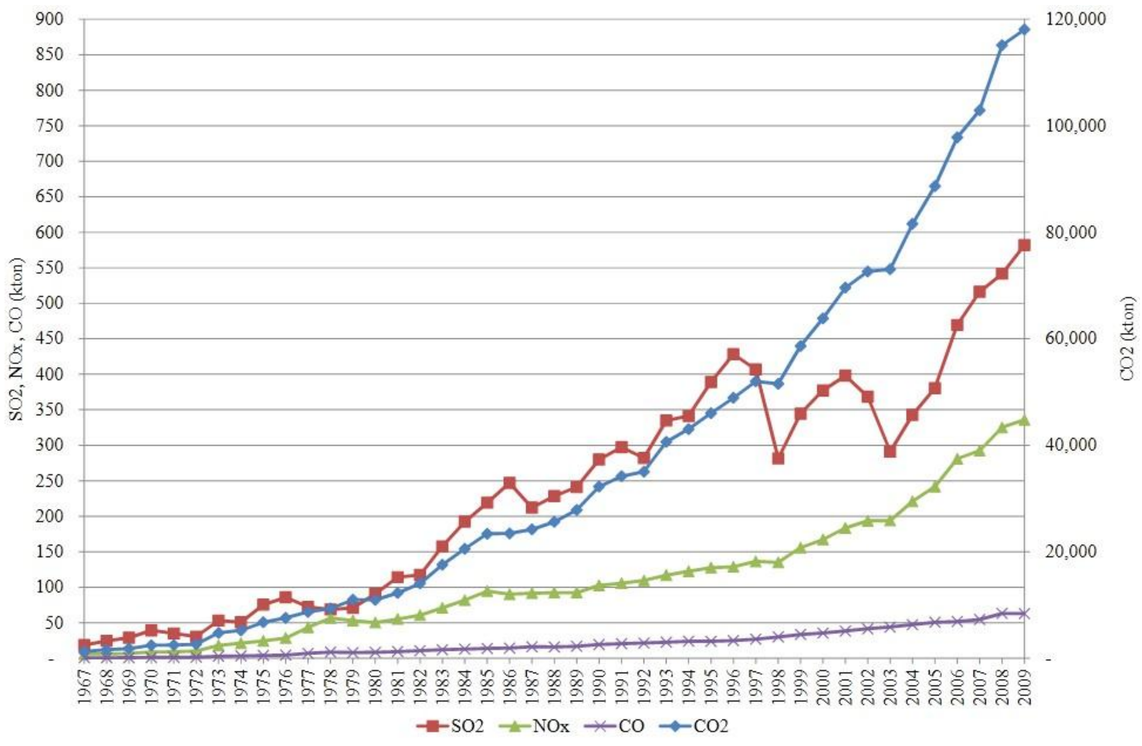


Figure 4-10. Total emission in Iranian power plants from 1967 to 2009

Table 4.8. Fuel types contribution (%) in total emission and total energy consumed in power plants in 2009

Fuel type	Pollutant	Steam turbine		Gas turbine		Combined cycle	
		Emission	Energy	Emission	Energy	Emission	Energy
Natural gas	CO_2	51.01	59.59	76.39	82.23	82.53	87.11
	SO_2	0.03		0.47		0.68	
	NO_x	55.89		62.76		71.11	
	CO	78.17		99.14		99.41	
Diesel	CO_2	0.23	0.19	23.61	17.77	17.47	12.89
	SO_2	0.09		99.53		99.32	
	NO_x	0.15		37.24		28.89	
	CO	0.11		0.86		0.59	
Fuel oil	CO_2	48.76	40.21	-	-	-	-
	SO_2	99.88		-		-	
	NO_x	43.96		-		-	
	CO	21.72		-		-	

The emissions per unit electricity generation in power sector is calculated using Eq. (3-10) and the results are tabulated in Table 4.9 and shown in Figure 4-11.

Table 4.9. Emission per unit of electricity generation (kg/kWh) from 1967 to 2009

Year	CO_2	SO_2	NO_x	CO
1967	0.7026	0.0101	0.0032	0.0004
1968	0.6589	0.0101	0.0025	0.0003
1969	0.5722	0.0091	0.0021	0.0003
1970	0.5744	0.0092	0.0021	0.0003
1971	0.4518	0.0064	0.0017	0.0002
1972	0.3835	0.0044	0.0015	0.0002
1973	0.5115	0.0057	0.0019	0.0003
1974	0.4682	0.0046	0.0019	0.0003
1975	0.5292	0.0059	0.0019	0.0003
1976	0.5337	0.0060	0.0020	0.0003
1977	0.5537	0.0046	0.0028	0.0004
1978	0.5374	0.0040	0.0033	0.0005
1979	0.5652	0.0037	0.0027	0.0004
1980	0.5520	0.0046	0.0025	0.0004
1981	0.5473	0.0051	0.0025	0.0004
1982	0.5344	0.0045	0.0023	0.0004
1983	0.5758	0.0052	0.0023	0.0004
1984	0.6033	0.0056	0.0024	0.0004
1985	0.6368	0.0060	0.0026	0.0004
1986	0.6004	0.0063	0.0023	0.0004
1987	0.5691	0.0050	0.0022	0.0004
1988	0.5853	0.0052	0.0021	0.0004
1989	0.5716	0.0049	0.0019	0.0003
1990	0.5874	0.0051	0.0019	0.0004
1991	0.5723	0.0050	0.0018	0.0003
1992	0.5478	0.0044	0.0017	0.0003
1993	0.5696	0.0047	0.0016	0.0003
1994	0.5583	0.0044	0.0016	0.0003
1995	0.5751	0.0049	0.0016	0.0003
1996	0.5699	0.0050	0.0015	0.0003
1997	0.5634	0.0044	0.0015	0.0003
1998	0.5265	0.0029	0.0014	0.0003
1999	0.5472	0.0032	0.0015	0.0003
2000	0.5390	0.0032	0.0014	0.0003
2001	0.5473	0.0031	0.0014	0.0003
2002	0.5272	0.0027	0.0014	0.0003
2003	0.4881	0.0019	0.0013	0.0003
2004	0.5009	0.0021	0.0014	0.0003
2005	0.4979	0.0021	0.0014	0.0003
2006	0.5080	0.0024	0.0015	0.0003
2007	0.5045	0.0025	0.0014	0.0003
2008	0.5368	0.0025	0.0015	0.0003
2009	0.5335	0.0026	0.0015	0.0003

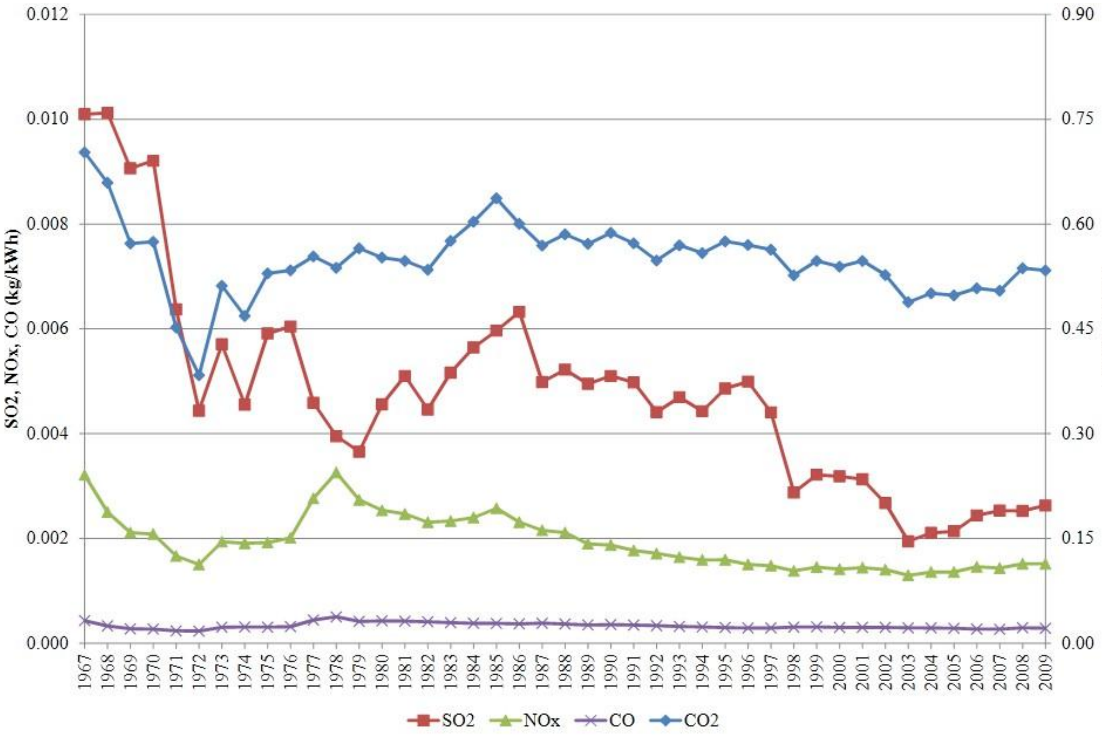


Figure 4-11. Emission per unit electricity generation from 1967 to 2009

For 9 years (2001 to 2009), there was detailed information of the fuel consumed and electricity generated for all types of power plants. Therefore, the amount of total emissions and emissions per unit of electricity generation in each type of power plant were calculated more precisely. These data were calculated by using Eqs. (3-8) and (3-11) and tabulated in Table 4.10 and Table 4.11.

Table 4.10. Total emission (kton) in thermal power plants from 2001 to 2009

Year	Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
2001	CO_2	48,141	13,965	7,219	272	69,598
	SO_2	384	10	3	0	398
	NO_x	104	49	24	7	184
	CO	24	8	5	2	38
2002	CO_2	48,215	12,384	11,755	296	72,650
	SO_2	355	10	3	1	368
	NO_x	105	44	37	8	194
	CO	25	7	8	2	42
2003	CO_2	47,866	12,100	12,849	235	73,050
	SO_2	279	8	3	0	291
	NO_x	106	42	40	6	194
	CO	26	7	9	1	44
2004	CO_2	50,649	16,627	14,085	213	81,574
	SO_2	324	13	5	0	343
	NO_x	111	59	45	6	221
	CO	27	10	9	1	47
2005	CO_2	52,833	21,400	14,258	169	88,661
	SO_2	358	17	6	0	380
	NO_x	116	75	46	5	242
	CO	28	12	9	1	51
2006	CO_2	53,234	27,812	16,594	177	97,817
	SO_2	429	30	11	0	470
	NO_x	115	104	57	5	281
	CO	26	14	10	1	52
2007	CO_2	55,133	24,084	23,506	180	102,903
	SO_2	477	20	19	0	516
	NO_x	118	86	83	5	292
	CO	26	14	14	1	55
2008	CO_2	57,530	34,308	23,152	161	115,150
	SO_2	503	26	12	0	542
	NO_x	124	121	77	4	325
	CO	27	20	15	1	63
2009	CO_2	57,337	33,569	27,073	101	118,079
	SO_2	539	27	16	0	582
	NO_x	122	119	92	3	336
	CO	26	19	17	1	63

Table 4.11. Emission per unit electricity generation (kg/kWh) in thermal power plants from 2001 to 2009

Year	Emission	Steam turbine	Gas turbine	Combined cycle	Diesel engine
2001	CO_2	0.5765	0.6864	0.4033	0.8290
	SO_2	0.0046	0.0005	0.0002	0.0015
	NO_x	0.0012	0.0024	0.0013	0.0223
	CO	0.0003	0.0004	0.0003	0.0048
2002	CO_2	0.5722	0.7064	0.4261	0.8328
	SO_2	0.0042	0.0006	0.0001	0.0015
	NO_x	0.0012	0.0025	0.0013	0.0224
	CO	0.0003	0.0004	0.0003	0.0048
2003	CO_2	0.5460	0.6837	0.3906	0.8086
	SO_2	0.0032	0.0005	0.0001	0.0014
	NO_x	0.0012	0.0024	0.0012	0.0217
	CO	0.0003	0.0004	0.0003	0.0047
2004	CO_2	0.5583	0.6657	0.3886	0.8450
	SO_2	0.0036	0.0005	0.0001	0.0015
	NO_x	0.0012	0.0023	0.0012	0.0227
	CO	0.0003	0.0004	0.0003	0.0049
2005	CO_2	0.5658	0.6661	0.3939	0.7984
	SO2	0.0038	0.0005	0.0002	0.0014
	NOx	0.0012	0.0023	0.0013	0.0214
	CO	0.0003	0.0004	0.0003	0.0046
2006	CO_2	0.5756	0.6745	0.4113	0.8066
	SO_2	0.0046	0.0007	0.0003	0.0014
	NO_x	0.0012	0.0025	0.0014	0.0217
	CO	0.0003	0.0004	0.0003	0.0047
2007	CO_2	0.5851	0.6405	0.4369	0.8008
	SO_2	0.0051	0.0005	0.0003	0.0014
	NO_x	0.0013	0.0023	0.0015	0.0215
	CO	0.0003	0.0004	0.0003	0.0046
2008	CO_2	0.5919	0.6248	0.4061	0.7896
	SO_2	0.0052	0.0005	0.0002	0.0014
	NO_x	0.0013	0.0022	0.0013	0.0212
	CO	0.0003	0.0004	0.0003	0.0046
2009	CO_2	0.5987	0.6234	0.4221	0.8146
	SO_2	0.0056	0.0005	0.0003	0.0014
	NO_x	0.0013	0.0022	0.0014	0.0219
	CO	0.0003	0.0004	0.0003	0.0047

The data for year 2009 in Table 4.10 is selected to show the share of each type of power plant for total emissions. The contribution of each type of thermal power plant in total emissions in 2009 is presented in Figure 4-12.

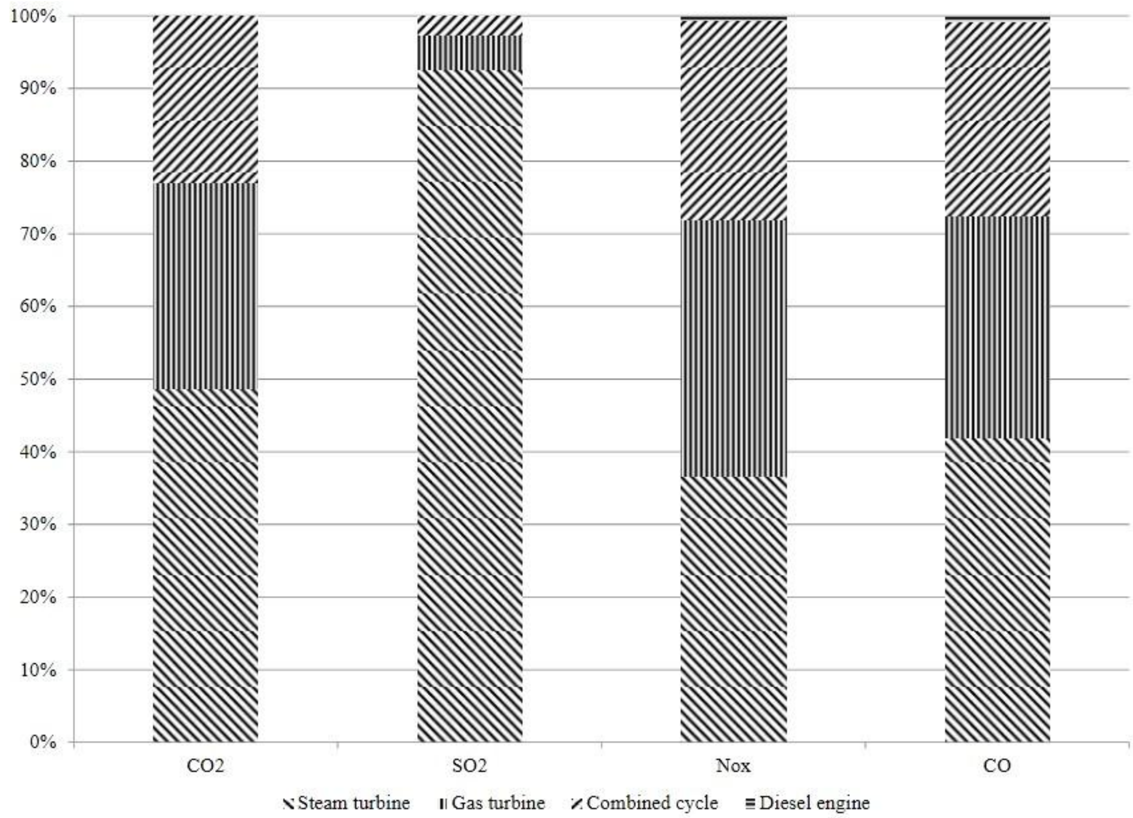


Figure 4-12. Power plants emission contribution (%) in 2009

4.2.1 Emissions per unit of electricity generation

Emissions per unit of electricity generated in the power plants are calculated using data from Table 3.1 and Table 4.6 in Eq. (3-19). The results are tabulated in Table 4.12.

Table 4.12. Average value of emission per unit of electricity generation in Iranian thermal power plants

	CO_2 (kg/kWh)	SO_2 (kg/kWh)	NOx (kg/kWh)	CO (kg/kWh)
Steam turbine	5.75×10^{-1}	4.44×10^{-3}	1.30×10^{-3}	2.88×10^{-4}

Gas turbine	6.64×10^{-1}	5.33×10^{-4}	2.36×10^{-3}	3.81×10^{-4}
Combined cycle	4.09×10^{-1}	1.96×10^{-4}	1.35×10^{-3}	2.64×10^{-4}
Diesel engine	8.13×10^{-1}	1.44×10^{-3}	2.18×10^{-2}	4.71×10^{-3}

4.3 Future power plants composition

Based on the polynomial curve fitting method described in the methodology chapter, the total power plant capacity for the coming years is estimated by the assessment of historical data from 1980 to 2009. Using Eq. (3-1) and the data in Table A - 1, the total nominal capacity equation is estimated by the following equation:

$$y = 64.715x^2 - 548.86x + 12287 \qquad R^2 = 0.988$$

Iran's historical nominal capacity for the past thirty years and its forecasted value until 2025 is shown in Figure 4-13.

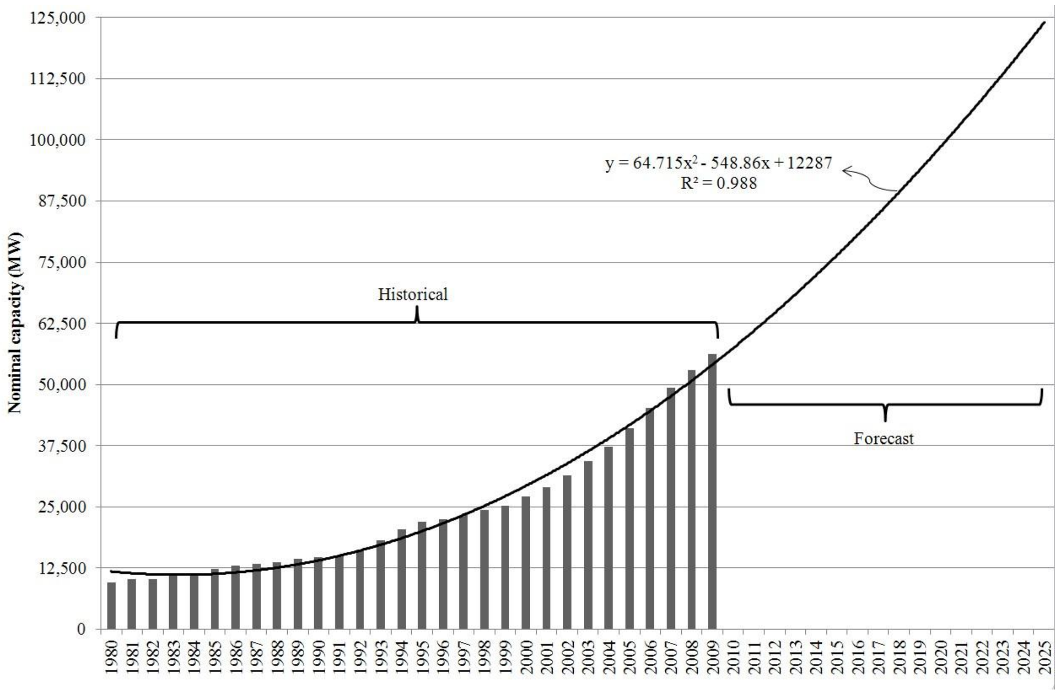


Figure 4-13. Historical data and forecasted nominal capacity of Iranian power plants from 1980 to 2025

Based on the future power plant composition, described in Chapter 2, the amount of nominal capacities in each type of power plant is calculated and presented in Table 4.13. Figure 4-14 shows the nominal capacities and their shares in new power plant composition in 2025. Figure 4-15 shows the pattern of nominal capacity composition from 2009 to 2025.

Table 4.13. Nominal capacity prediction in Iranian power plants from 2010 to 2025

Year	Steam turbine (MW)	Gas turbine (MW)	Combined cycle (MW)	Diesel engine (MW)	Coal-fired (MW)	Hydro power (MW)	Non-hydro renewables (MW)	Nuclear (MW)	Total (MW)
2010	15,704	18,790	13,861	425	95	8,049	161	378	57,463
2011	15,704	19,333	14,404	425	355	9,001	349	1,419	60,992
2012	15,704	19,896	14,967	425	625	9,988	545	2,498	64,649
2013	15,704	20,479	15,550	425	904	11,010	748	3,615	68,436
2014	15,704	21,082	16,153	425	1,193	12,067	957	4,771	72,353
2015	15,704	21,705	16,776	425	1,491	13,159	1,174	5,964	76,399
2016	15,704	22,348	17,419	425	1,799	14,286	1,397	7,196	80,574
2017	15,704	23,010	18,081	425	2,117	15,448	1,627	8,466	84,879
2018	15,704	23,693	18,764	425	2,444	16,645	1,865	9,774	89,313
2019	15,704	24,395	19,466	425	2,780	17,876	2,109	11,120	93,877
2020	15,704	25,118	20,189	425	3,126	19,143	2,360	12,505	98,570
2021	15,704	25,860	20,931	425	3,482	20,445	2,618	13,927	103,392
2022	15,704	26,622	21,693	425	3,847	21,781	2,883	15,388	108,344
2023	15,704	27,404	22,475	425	4,222	23,152	3,155	16,887	113,425
2024	15,704	28,207	23,278	425	4,606	24,559	3,434	18,425	118,636
2025	15,704	29,029	24,100	425	5,000	26,000	3,719	20,000	123,976

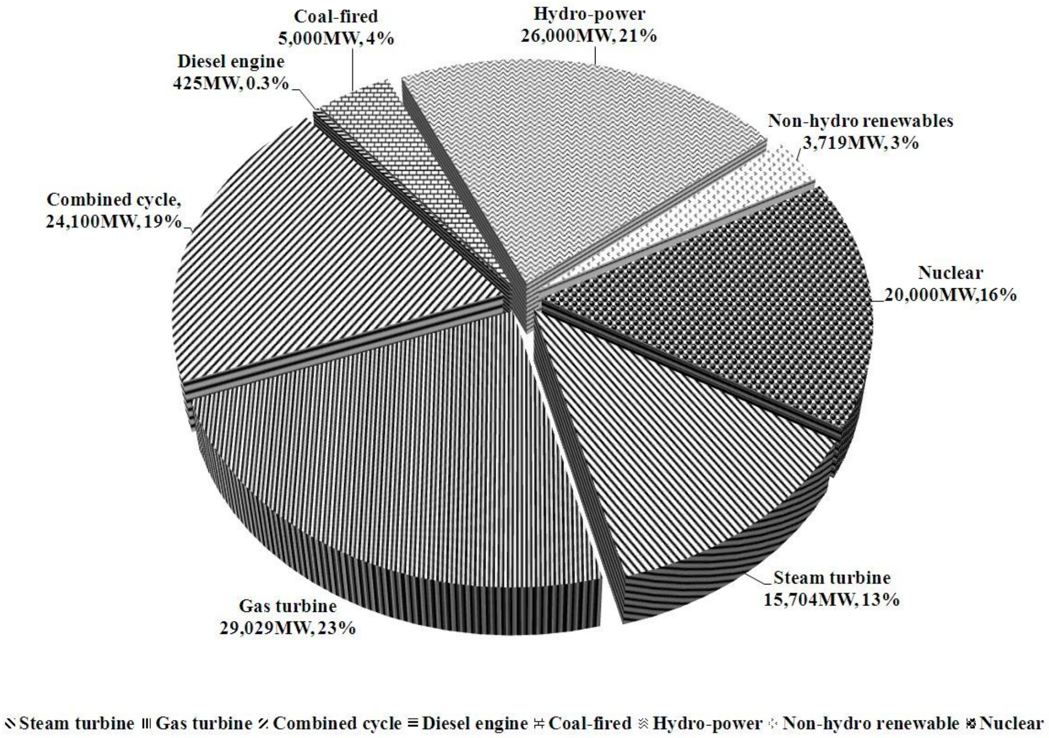


Figure 4-14. Nominal capacity (MW and %) in Iranian new power plant composition in 2025

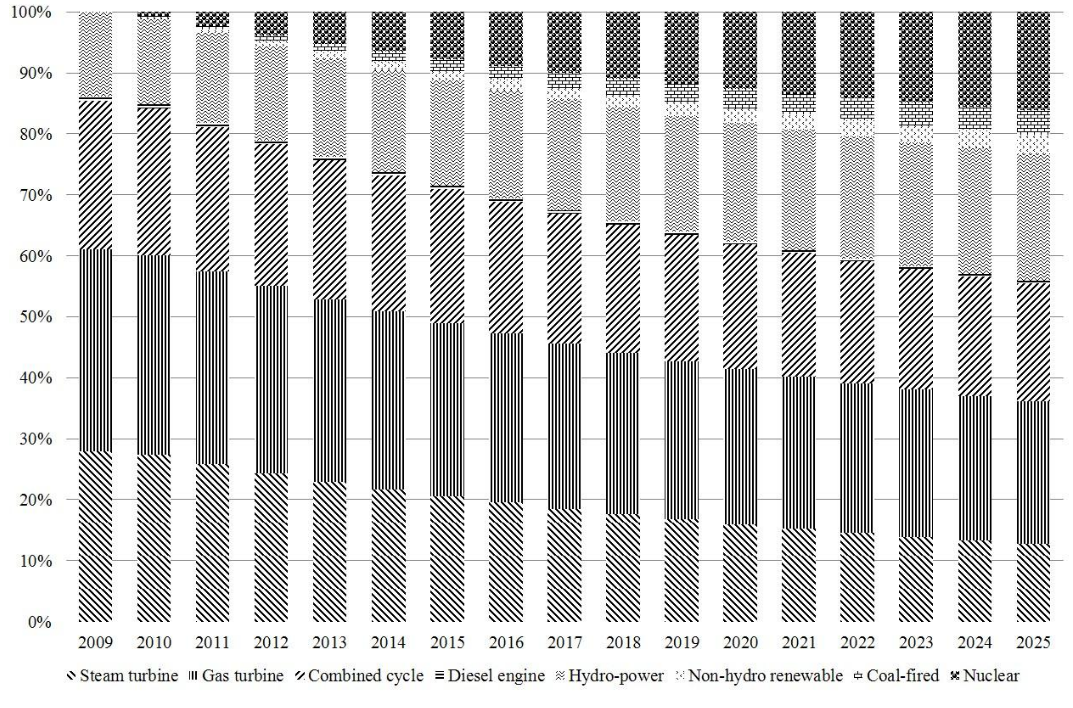


Figure 4-15. Pattern of nominal capacity for each type of power plants in Iran from 2009 to 2025

4.4 Future fuel consumption and prediction of emissions in power plants

4.4.1 Future fuel consumption

To calculate the future fuel consumption, it is necessary to estimate electricity generation in thermal power plants in the future. In the second scenario, electricity generation is estimated using Eq. (3-12) and the average capacity factor that was presented in Table 4.5, in Eq. (3-14). In the first and third scenarios, electricity generation was calculated using the capacity factor and future nominal capacities presented in Table 4.13, in Eq. (3-14).

All types of fuel consumption (including coal) in each type of thermal power plant in the future are calculated using Eq. (3-17). To calculate additional natural gas utilization in the third scenario and to compare with the first scenario, the fuel's calorific values are used in Eq. (3-18). Total fuel consumptions for all power plants for each scenario are tabulated in Table 4.14 and shown in Figure 4-16. It shows the amount of fossil fuels consumed in 2009 and the amount of fuels required for selecting each scenario in 2025.

Table 4.14. Fuel consumption prediction in thermal power plants in each scenario in 2025

	New composition (Scenario 1)	Old composition (Scenario 2)	Fuel switching (Scenario 3)
Natural gas (Mm^3)	63,611	99,652	79,366
Diesel (*Ml*)	7,401	10,149	140
Fuel oil (*Ml*)	7,321	16,156	-
Coal (*kton*)	10,826	-	10,826

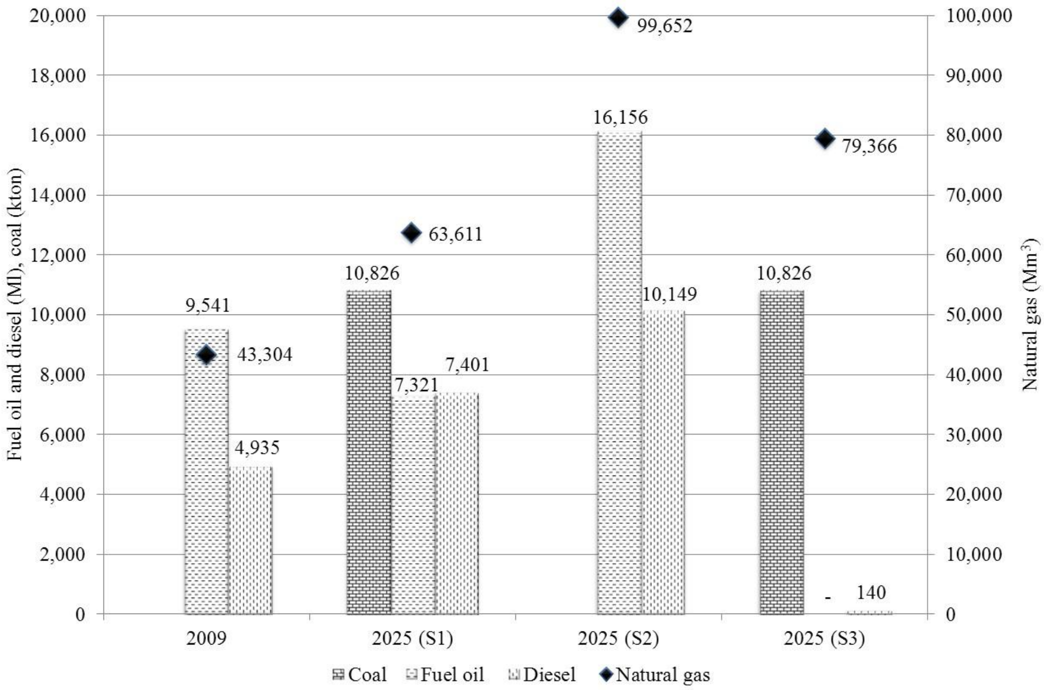


Figure 4-16. Power plants fossil fuel consumption in 2009 and three scenarios in 2025

4.4.2 Emissions in 2025

The amount of emissions is calculated using electricity generation predicted in thermal power plants and emissions per unit electricity generation in Iranian thermal power plants (Eq. (3-20)). In the fuel-switching scenario, total emissions are calculated using the emission factors and fuel consumption data in Eq. (3-21). The results are tabulated in Table 4.15 and presented in Figure 4-17 to Figure 4-20 for CO_2, SO_2, NO_x and CO respectively.

Table 4.15. Emissions in 2009 and emissions prediction in each power plant and each scenario in 2025

Emission (ton)	Year (scenario)			
Power plant type	2009	2025 (S1)	2025 (S2)	2025 (S3)
CO_2				
Steam turbine	57,386,356	53,666,601	118,427,776	47,210,496
Gas turbine	33,612,842	51,296,603	72,504,056	47,665,692
Combined cycle	27,111,770	48,583,157	60,786,094	46,542,970
Diesel engine	100,836	180,932	399,267	180,932
Coal-fired	-	33,617,610	-	33,617,610
Total	118,211,804	187,344,902	252,117,194	175,217,699

Table 27, continued. Emissions in 2009 and emissions prediction in each power plant and each scenario in 2025

Emission (ton)	Year (Scenario)			
Power plant type	2009	2025 (S1)	2025 (S2)	2025 (S3)
SO_2				
Steam turbine	539,889	414,676	915,079	968
Gas turbine	26,886	41,154	58,169	232
Combined cycle	16,075	23,221	29,053	227
Diesel engine	178	320	706	320
Coal-fired	-	396,004	-	396,004
Total	583,028	875,375	1,003,007	397,750
NO_x				
Steam turbine	122,411	121,454	268,016	110,442
Gas turbine	119,144	181,926	257,139	138,664
Combined cycle	91,616	159,706	199,821	135,398
Diesel engine	2,711	4,865	10,736	4,865
Coal-fired	-	148,145	-	148,145
Total	335,883	616,097	735,712	537,514
CO				
Steam turbine	26,277	26,860	59,273	33,092
Gas turbine	19,317	29,453	41,629	35,533
Combined cycle	16,786	31,279	39,136	34,696
Diesel engine	584	1,048	2,313	1,048
Coal-fired	-	5,698	-	5,698
Total	62,964	94,338	142,351	110,066

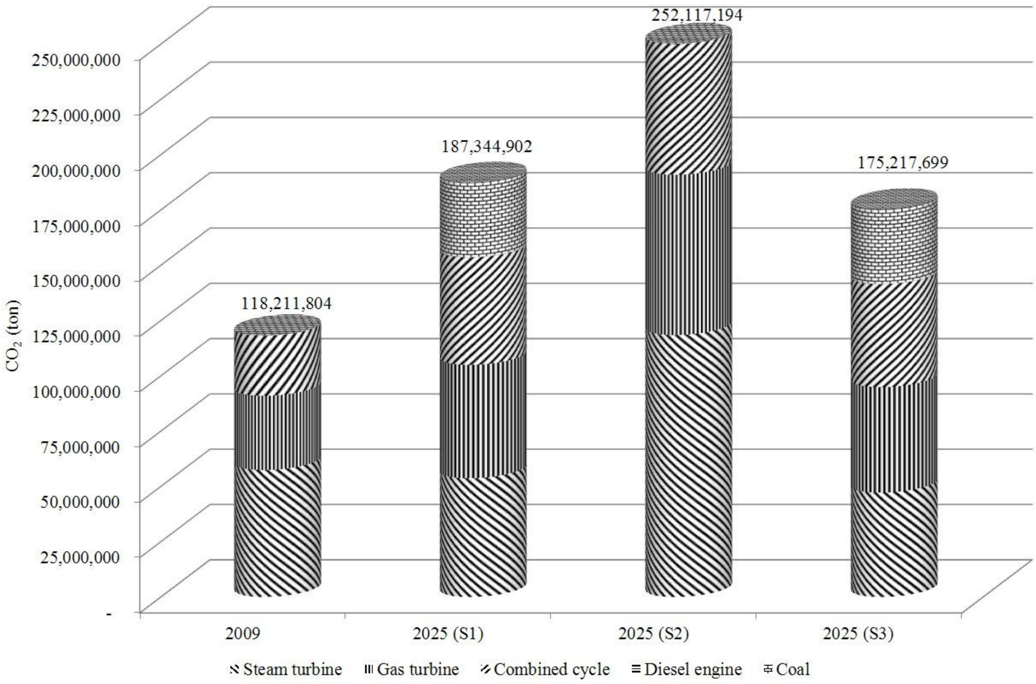


Figure 4-17. CO_2 emission for each type of power plants in 2009 and three scenarios in 2025

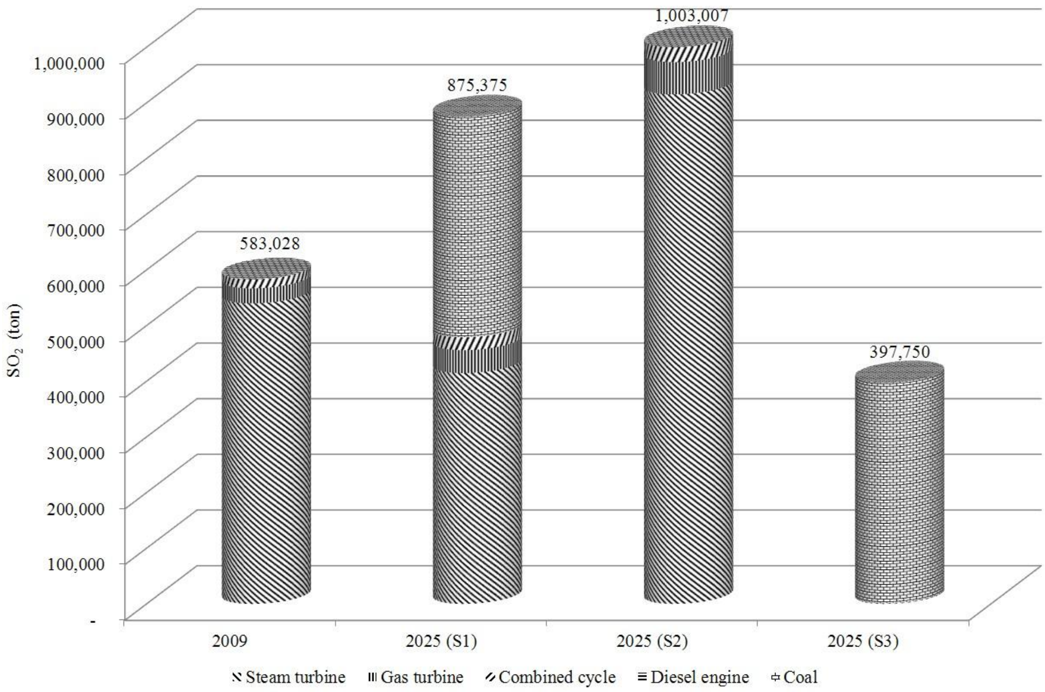


Figure 4-18. SO_2 emission for each type of power plants in 2009 and three scenarios in 2025

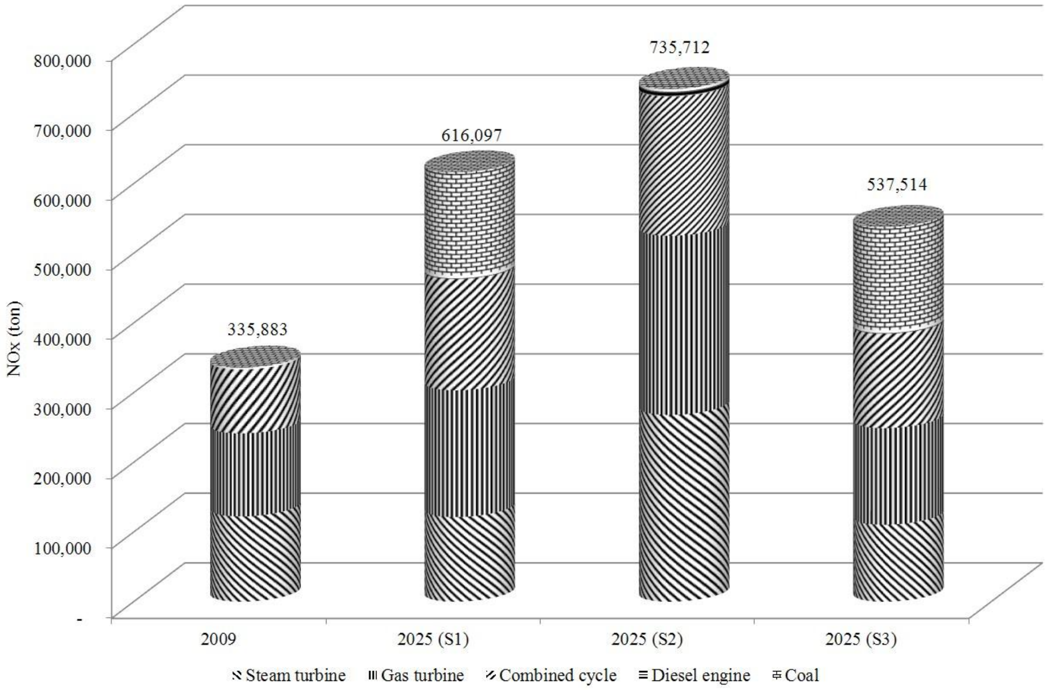


Figure 4-19. NO_x emission for each type of power plants in 2009 and three scenarios in 2025

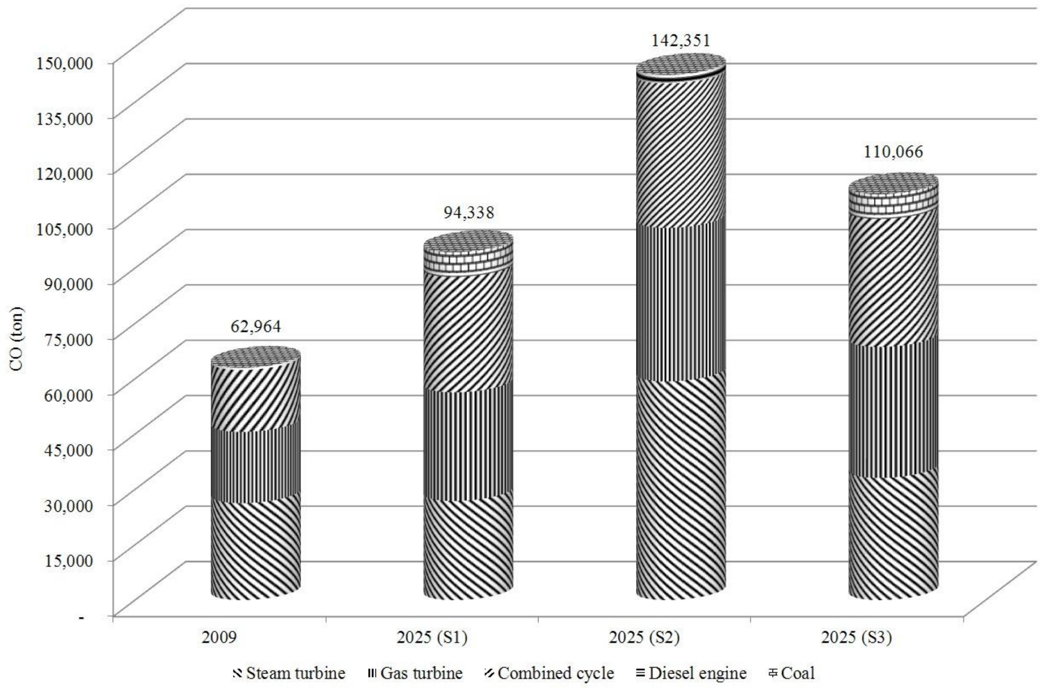


Figure 4-20. CO emission for each type of power plants in 2009 and three scenarios in 2025

4.5 Electricity price

In this study to estimate levelized electricity cost generated in power plants the major costs capital, operation and maintenance (fixed and variable) and fuel have been considered. Due to uncertainties, the minimum and maximum costs have been considered in the calculations, and, accordingly, a range of results has been estimated. The levelized electricity cost generated in each type of power plant in Iran was calculated using data from Table 3.3 and Eq. (3-23). The range of results are tabulated in Table 4.16 and shown in Figure 4-21, and the amount and share of medium levelized electricity cost are presented in Figure 4-22 and Figure 4-23.

Table 4.16. Levelized electricity cost ($/MWh) in power plants by cost types.

	Capital cost		OMC		Fuel cost		Total cost		
	Min	Max	Min	Max	Min	Max	Min	Max	Average
Steam turbine	16	41	4	30	10	19	30	90	60
Gas turbine	34	105	5	37	12	23	50	165	108
Combined cycle	14	43	2	7	8	16	27	66	46
Coal-fired	32	109	5	14	23	23	59	146	103
Nuclear	61	151	2	22	7	7	70	180	125
Hydro-power	67	792	7	29	0	0	74	822	448
Wind turbine	60	194	4	33	0	0	64	226	145
Geothermal	30	96	8	54	0	0	38	150	94
Photovoltaic	338	1043	3	39	0	0	341	1082	712
Solar thermal	126	427	12	31	0	0	138	459	299

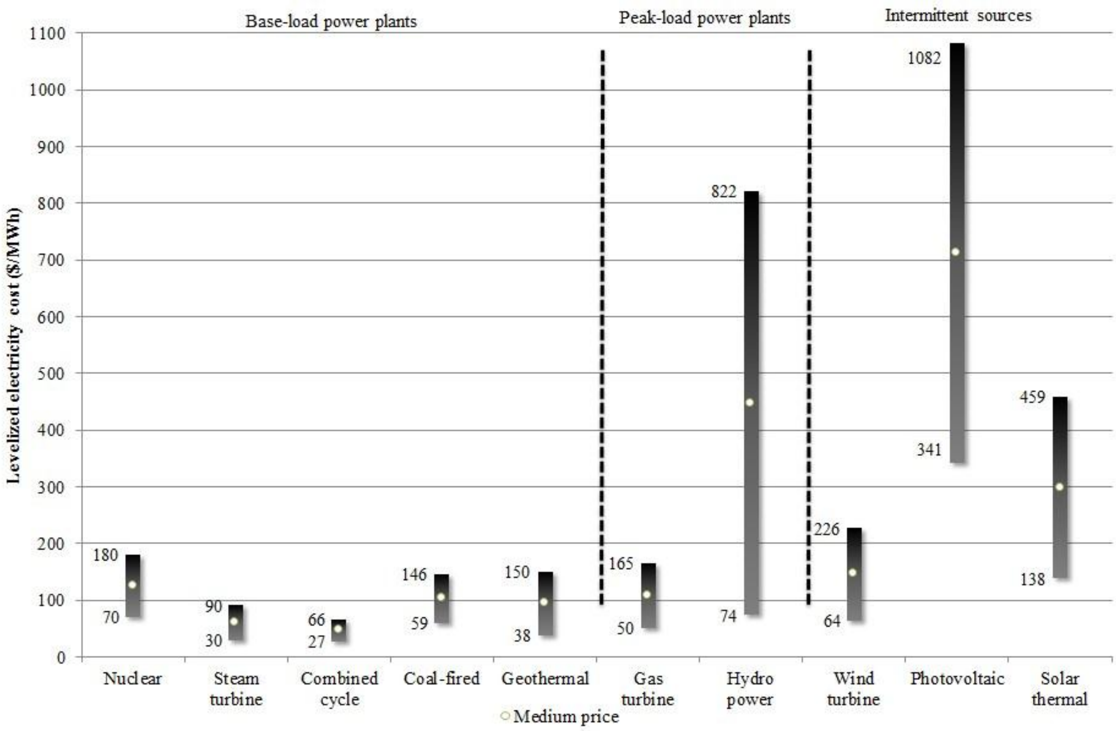


Figure 4-21. Levelized electricity cost range ($/MWh) in different power plants

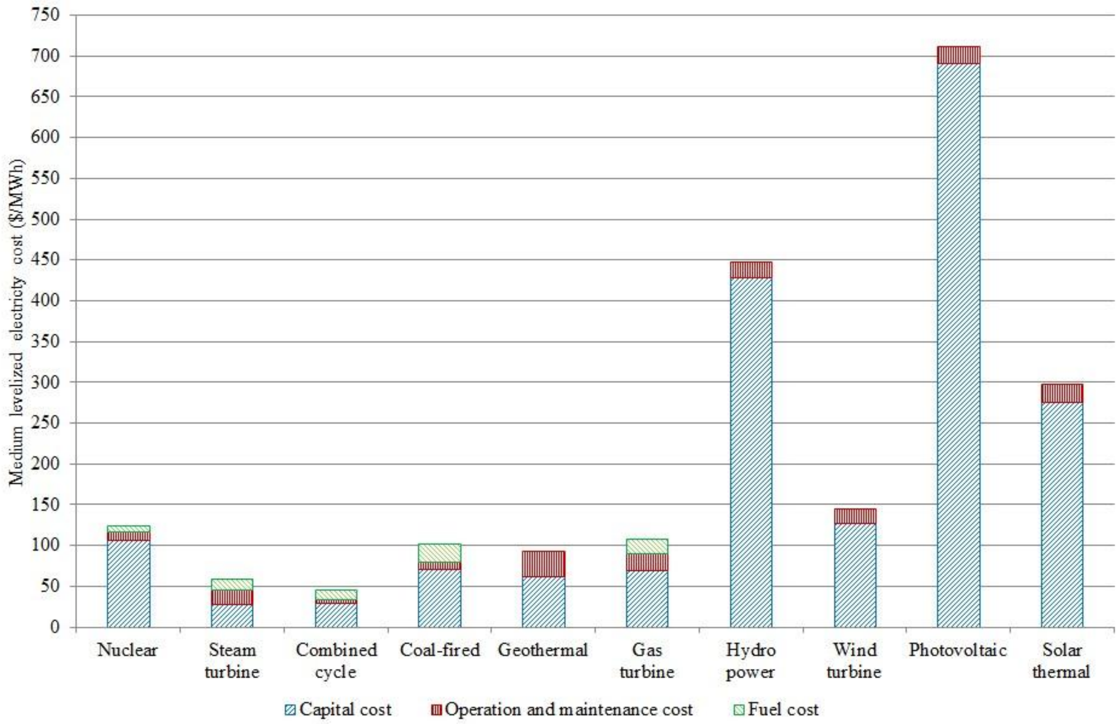


Figure 4-22. Medium levelized electricity cost in power plants by cost types

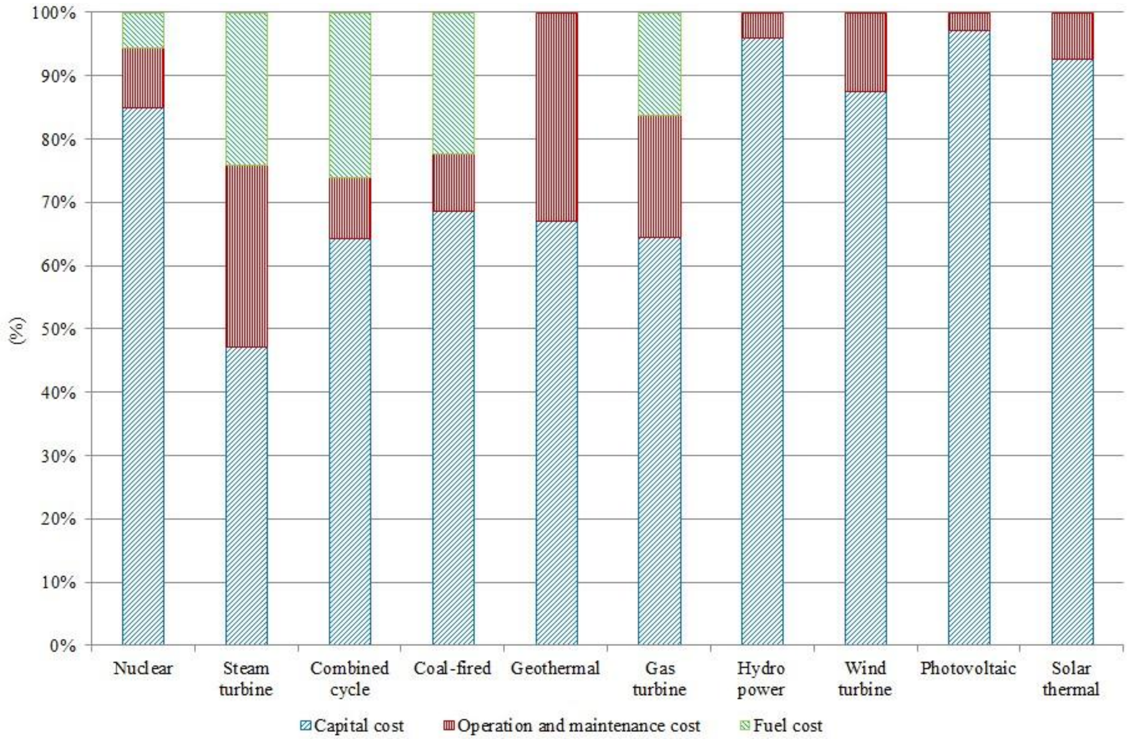


Figure 4-23. Shares of each cost type on total levelized electricity cost in power plants

4.5.1 Impact of environmental issues on electricity price

Recently, in some analyses, carbon price has been taken into account such as mechanisms under the Kyoto Protocol to encourage countries to contribute to emission reduction efforts. The carbon price is considered as a key tool for emissions reduction in the future and may affect the advantages and disadvantages of power plants. If Iran wants to consider the effect of this price on total electricity cost, the values tabulated in Table 4.17 should be added to the previous costs. This table has been driven by using Eq. (3-25) and Table 4.12. It shows that by considering $20 per each dioxide carbon metric ton, 11.5, 13.3, 8.2 and 23.6 $/MWh should be added to the electricity cost generated by steam turbines, gas turbine, combined cycle and coal-fired respectively.

Table 4.17. Impact of carbon price on electricity generation cost ($/MWh) in Iran

Power plant type	Carbon price ($/ton CO_2)		
	10	20	30
Steam turbine	5.75	11.5	17.25
Gas turbine	6.64	13.28	19.92
Combined cycle	4.09	8.18	12.27
Coal-fired	11.8	23.6	35.4

The same process can be done to quantify the environmental effect of power plants such as emissions other than CO_2 in fossil fuel based types and even radioactive radiation risk in nuclear power plants or nuclear used fuel waste management. The weight of each of them on decision making, depend on the government environmental policy or country's international commitments.

Chapter 5 :

Discussions

5.1 Power sector composition

As shown in the Figure 4-1 and Figure 4-2, the annual electricity production growth in the country was 12.1%, and the annual nominal capacity growth was 10.2%. This is equivalent to an annual growth of 5,225 MWh of electricity production that needs to create 1,315 MW of new power generation capacity annually.

For 43 years, from 1967 to 2009, the average of population growth in Iran was 2.5%. Nonetheless, the per-capita electricity consumption increased by about 4,200%, which is equivalent to an average annual growth rate of 9.3%. Electricity consumption per person increased from 71 kWh in 1967 to 3,000 kWh in 2009. This very high growth is due to the economic growth that caused the rate of electricity production to be much higher than the population growth.

As power plants were developed a long time ago, their structure has also been changed from time to time to meet the current electricity demands of the country. Figure 4-5 shows the change in the pattern of nominal capacity composition from 1967 to 2009. This figure shows that in the last two decades (1989-2009), the share of the steam power plants decreased from 56% to 28%, while the share of the gas turbine and combined cycle together have increased from 25% to 57%. The reasons for these changes are the enormous gas resources in the country, high efficiency, and fewer emissions when natural gas is used in combined cycle power plants compared to other thermal types.

Figure 4-4 shows that the electricity generation from fossil fuel is much higher than renewable resources. This is due to the tendency to use more fossil fuel power plants in order to meet high electricity demand. This is also due to the huge fossil fuel resources in the country, deficiency of water resources and lack of investment in renewable sources. There have been some changes in the pattern of thermal power plants. Since 2001, many gas turbines and combined cycle power plants were developed; therefore, the contribution of electricity production by these power plants has been increased. This is due to the government's policy to increase the contribution of gas turbine and combined cycle plants. While the diesel engine power plants are slowly being phased out in Iran, the share of the nominal capacity or electricity generation of this type of power plant decreased from 21% in 1967 to 0.1% in 2009. Meanwhile, the contribution of hydropower plants has been consistently decreasing from 40% in 1971 to 13.7% in 2009. Unlike steam turbine and combined cycle power plants, the share of electricity production from the hydropower plants was always less than its nominal capacity because of drought and limited water resources.

The share of each type of power plant in nominal capacity and electricity generation in 2009 is tabulated in Table 4.4 and is shown in Figure 4-6. This shows that in 2009, about 85% of nominal capacities and more than 96% of electricity produced was by three types of thermal power plant; gas turbine, combined cycle and steam turbine. Although hydropower plants have 13.7% of nominal capacity, because of the water shortage in the country, only about 3.3% of the electricity is generated by this type.

Iran has great potential for generating electricity from wind and solar sources; however, the amount of electricity generated from these resources is still very small. Although since 2001 there has been a 30% annual growth rate in electricity generation from wind turbines, less than 0.1% of total electricity is generated from this source.

Several components influence the power plant capacity factors, including life span, purpose, overhaul maintenance, fuel supply, and technology used in power plants.

Figure 4-7 shows that this factor for the base-load (e.g., steam turbine) and peak-load power plants, which were usually added to the network at the peak electricity demand hours. The average capacity factors for steam turbine, gas turbine, combined cycle and diesel engines have been evaluated at 67.8%, 30.3%, 56.2% and 6.0%, respectively. In this study, the capacity factor of the coal-fired power plants is assumed to be 65.0% (Energy Information Administration, 2010a).

5.2 Emission Production

The growth of all types of fuel consumed by Iranian power plants has been depicted in the Figure 4-8. Natural gas is expected to be the fastest growing component of world energy consumption (International Energy Outlook 2002 with projection to 2020, December 2001). This figure shows that natural gas consumption growth is more than other types of fuel in Iranian thermal power plants. The average annual growth of natural gas was 20%, while fuel oil and diesel were 9% from 1967 to 2009.

Figure 4-9 also shows the share of total energy for each fuel type used in Iranian thermal power plants. It shows that the contribution of natural gas increased from 3% in 1967 to 73% in 2009. This share can increase more by supplying natural gas in the winter when some power plants switch to liquid fuels because of the pressure drop in gas pipelines.

For these 42 years (1967 to 2009), the average annual growth rate of emissions was 11% for CO_2, 9% for SO_2, 10% for NO_2 and 11% for CO. Emission fluctuations in some years are due to the change in the amount and type of fuel used. Fuel use changes might be due to the rate of exploitation of hydropower plants, replacement of natural gas with liquid fuel in some cases and because of overhaul and maintenance in some old power plants. As seen in Figure 4-10, decreases in CO_2 and SO_2 emissions were observed due to a decrease in the liquid fuel consumption. For instance, in 1998 and

2003, while the liquid fuel consumption decreased, especially fuel oil (Figure 4-8), CO_2 and SO_2 emissions also decreased.

The year 2009 is considered as a sample to show that the emissions in power plants are more due to the use of liquid fuels. For example, as resulted in Table 4.8 although about 18% of thermal energy used in gas turbine power plants is from diesel respectively, more than 24%, 37% and 99% of CO_2, NO_x and SO_2 were emitted due to consumption of this type of fuel. These results are almost the same for the diesel used in the combined cycle power plants, and for the fuel oil used in the steam turbine power plants. Therefore, if the use of liquid fuels in thermal power plants can be avoided, the amount of SO_2 emitted in these power plants will be decreased significantly.

The important point observed from results depicted in Figure 4-11 is that the trend of emissions per unit electricity generation is decreasing. This is due to more natural gas being used instead of liquid fuels and the increase in the thermal power plant efficiency. Increasing the efficiency of thermal power plants was caused by replacing the gas turbine power plants with combined cycle and by increasing the efficiency of new turbines.

The Figure 4-12 shows that the contribution of diesel engines for all types of emission was insignificant. Comparison of the thermal power plants with regard to emissions shows that the worst type is the steam turbine, which produces the highest amount of emissions while the best type is the combined cycle. Except for the NO_x emissions, for which both the gas turbine power plant and steam turbine have the same emission, in this comparison, the diesel engine is eliminated due to the insignificant share of electricity generation.

The data for Table 4.12 have been calculated by using the past 8-year fuel mix. Therefore, by changing the fuel mix used in thermal power plants, this data will be changed. For example, by increasing the contribution of natural gas in power plants, the emissions per unit of electricity generated will be decreased. The results show that the combined cycle power plant is the best thermal type in terms of greenhouse gas emissions. The results found are also similar to the data that was experimentally calculated using analysis and measurement of flue gases of Iran’s fossil fuel power plants (steam turbine, gas turbine and combined-cycle types) (Nazari et al., 2010).

5.3 Future power plant composition

Iran's historical nominal capacity for the past thirty years and its forecasted value until 2025 is shown in Figure 4-13. Accordingly, the total capacity of Iranian power plants in 2025 is estimated to be about 124,000 MW. This value shows that the expected demand for electricity during the coming 16 years would require the installation of as many power plant capacities as installed in the entire past forty years. It is equivalent to the construction of 4,200 MW nominal capacities each year, which is very high in contrast with the annual 2,900 MW capacity increase over the last decade. It also shows that in order to maintain the trend of the country’s power sector development, the annual growth of 5.1% of the nominal capacity in power plants is required until 2025. This trend will increase the nominal capacity per-capita from 762 W in 2009 to 1300 W in 2025 and electricity generation per-capita will also increase from 3000 kWh to 5700 kWh.

Figure 4-14 shows the nominal capacities and their shares in new power plant composition in 2025. Figure 4-15 shows the pattern of nominal capacity composition from 2009 to 2025. These figures show that power plant diversity will increase to ten (five thermals, four renewables and a nuclear). They also show that the share of thermal power plants will decrease from 85% to 60% in the new power plant composition in the future.

5.4 Future fuel consumption and prediction of emissions in power plants

Future power sector's fossil fuel consumption has been presented in Table 4.14 and shown in Figure 4-16. The results show that in the new power plant composition (first scenario); the consumption of natural gas will increase by 47% and diesel by 50%. In addition, coal consumption in coal-fired power plants will reach 10,826 ktons. The total coal production in the country in 2008 was about 2,736 ktons. Therefore, providing this amount of coal to use in coal-fired power plants will require a huge amount of investment to increase production or imports (Ministry of Energy, 2009c).

In the second scenario where the same composition of power plants as in 2009 is assumed, all types of fuel consumption will increase by 130%, 106% and 69% for natural gas, diesel and fuel oil respectively. Meanwhile, in the third scenario, with the replacement of liquid petroleum with natural gas, in 2025 only the consumption of 7,321 Ml fuel oil is eliminated, and diesel consumption is decreased by 97 vol%, which is equivalent to 7,261 Ml. However, natural gas consumption will increase 15,755 Mm^3. In view of fuel supply in this scenario, theoretically it is possible for the country to switch fuel to natural gas, because Iran is rich in natural gas resources, which is used by many power plants. Nevertheless, it should be made available over the year, especially in the winter when domestic consumption is maximum. In addition, it is necessary for those that previously did not use natural gas to construct pipelines and to technically prepare them to use this type of fuel.

CO_2 emissions

Figure 4-17 presents CO_2 emissions from the electricity sector in Iran in different scenarios compared with emissions in 2009. The results show that in the new composition (first scenario) CO_2 emissions are 1.6 times higher than those in 2009. If the old structure of electric power industries continues (second scenario), CO_2 emissions will increase 2.1 times by 2025. This means that the new composition, including 20,000 MW nuclear power plants will cause 26% CO_2 abatement in comparison with the current power plant mix in 2025. In addition, the results of scenario 3 show that after natural gas substitutions, the total emissions will be reduced by 6%. The share of coal-fired power plants in total CO_2 emissions will be 18% because the coal-fired has the highest emissions among the thermal types. By substituting it with combined cycles, Iran can also decrease another 9% of CO_2 emissions.

SO_2 emissions

The results of SO_2 emissions in different scenarios are presented in Figure 4-18. The rate of SO_2 in the new power plant composition will increase by 50% and in the second scenario it will be up to 72% compared with the amount in 2009. In the third scenario by eliminating or reducing the use of sulfur-containing fuels such as fuel oil and diesel, the amount of emissions decreased 55% compared with the use of the new composition and 32% less than the amount in 2009. In this scenario, the SO_2 emissions are mostly due to coal-fired power plants, which use a huge volume of coal containing large amounts of sulfur. In order to reduce SO_2 emissions other methods such as elimination or reduction of sulfur in the fuel or using the flue gas desulfurization (FGD) for removing SO_2 from the exhaust flue gases should be adopted (Wikipedia, 2010). Withdrawing to construct or substituting the coal-fired type with the combined cycle is also another alternative for eliminating SO_2 in the future.

NO_x emissions

The NO_x emissions by power plants in different scenarios are given in Figure 4-19. The results show that NO_x emissions will increase 83% until 2025 for the new power plant composition and if the composition does not change, this will increase to 119%. By natural gas substitution, the NO_x emissions will decrease about 13% in comparison with the first scenario.

CO emissions

The CO emissions in each scenario are shown in Figure 4-20. The figure shows that the amount of CO emissions in the first scenario will be 1.5 times higher and in the second scenario, 2.3 times higher than the amount in 2009. Therefore, for CO emissions, it seems that the new power plant structure is better than the old one. Nevertheless, if liquid petroleum is replaced by natural gas, the power plants will produce more CO emissions about 17% higher than the first scenario or equivalent to 1.7 times in 2009.

5.5 The electricity price

In terms of medium levelized electricity cost, the results presented in Table 4.16 Figure 4-21, show that the best base-load power plants are the combined cycle, steam turbine, geothermal, coal-fired and nuclear, respectively. For peak-load power plants, the foremost types are gas turbine and hydropower. Among the intermittent sources, wind turbines generate the cheapest electricity price. Solar thermal, and photovoltaic are ranked number two and three respectively. These estimations are based on the medium of the range of results. There are many factors, which can effect on actual electricity cost in top or bottom this range for each alternative.

There are also some determinant costs, which are not considered in this calculation but will contribute to the overall costs such as transmission and distribution network costs, decommissioning and waste disposal management and liability for nuclear damage. Iran has some abilities that cause a decrease on capital cost such as low labor cost, and also governmental support. For sensitivity analysis, variation of some factors should be taken into account. For instance, the two-digit inflation rate in Iran can affect the real interest rate which plays a critical role in the levelized electricity cost, especially for high capital cost and long construction time power plants such as nuclear. The local technology will probably decrease the electricity price generated by thermal, solar thermal and hydro power types, due to the good experience in manufacturing these types and their ancillary equipment in Iran (Dehqan, 2010; Mehdi, 2011). For coal-fired and nuclear types, Iran does not have the local technology and has to adopt foreign technology. This issue will probably increase the electricity cost generated by these power plants. This is especially evident for NPP, where many countries or companies are reluctant to deal with Iran due to the U.S. or United Nations Security Council (UNSC) sanctions. Dependency on foreign technology and cooperation are the main reasons to prolong its construction time in Iran. For instance, the first nuclear power plants which restarted construction, were completed after 16 years while the normal construction time is 6 years. Moreover, according to Katoozian, the Head of the Energy Commission of the Iranian parliament, Russia charged Iran more than 150% of normal price (Katoozian, 2011). In terms of fuel availability criteria, Iran has good access to natural gas to use in power plants, but would probably have to import more coal to use in a coal-fired type. There are also some limitations on operating hydropower plants because of drought, leading to the low capacity factor (about 11% in 2009). These results may vary in the future by developing technologies. For example, the electricity price generated by renewable energy technologies such as photovoltaic, solar and wind are decreasing, and, consequently these types will be more comparable with nuclear or even thermal types (Blakburn et al., 2010).

There are some factors, which can make nuclear electricity comparable with thermal types in the future. The first factor is the ability to export natural gas to the international market. This goal can be reached by achieving LNG technology or by connecting to new markets by pipeline. After that the natural gas price will increase in thermal power plants and will affect the electricity cost generated by them. Another factor is the interest rate, which is high in the country at present. This factor has a considerable effect on nuclear electricity because of the considerable capital cost. That is why in the countries with low interest rates, (e.g., less than 5%) nuclear is comparable with thermal types. Therefore, by decreasing inflation, and, consequently, the interest rate in the country, the electricity cost will decrease in NPPs. Achieving the technology of nuclear reactor construction is necessary for a country to be independent of foreign countries, especially for Iran, which has local nuclear fuel cycle technology and wants to construct 20,000 MW of NPP.

As shown in Figure 4-23 about 85% of the electricity generation costs in nuclear power plants are fixed costs, where 9% is for operation and only 6% is for fuel cost. The share of capital cost for most renewable energy power plants is also high; however, for thermal power plants the running costs (including operation and maintenance cost and fuel cost) have a higher share. The results also shown that the most expensive electricity generated is by hydropower plants. One reason is the low capacity factor due to the limitations of hydropower in the country, and the second reason is the construction costs. Needless to say, dams are multi-purpose structures to save water for agricultural use, flood control as well as electricity generation. If only the share of electricity generation costs in capital, operation and maintenance were considered in the calculation, the electricity price in hydropower plants would decrease.

5.6 Impact of nuclear power on energy sustainability

Currently, many countries are endorsing nuclear power plant to increase their power capacity as an alternative to their primary energy dependency. Most of them do not have enough fossil fuel resources and strongly depend on imports. Based on the Nuclear non-Proliferation Treaty (NPT), the enrichment of uranium for a civilian nuclear program is a member’s undeniable right. There is also no absolute evidence in the reports of the International Atomic Energy Agency (IAEA) showing that Iran is intending to weaponize uranium (Campaign Against Sanctions and Military Intervention in Iran, 2010). Some international concerns exist about the main goal of the Iranian nuclear fuel cycle which can be used to make fuel or, in the highly extended form, the fissile core of an atomic weapon. These concerns have led to four sets of UNSC sanctions, and also some sanctions from the E.U. and U.S. over Iran’s refusal to suspend uranium enrichment. These sanctions have focused on restrictions of trade with Iran that would help the development of its nuclear technology (Smith, 2010). Although these sanctions, are not taken into account in the electricity price calculation in this study, it clearly has substantial direct and indirect effects on many aspects of the country, such as underdevelopment of the petrochemical and natural gas industries, high insurance cost, decreased foreign investment, unemployment, brain drain, decrease national currency value, political and military threat as well as foreign trade difficulties. Moreover, they will influence the cost of all related activities from production, conversion, enrichment, and fabrication. However, the results tabulated in Table 4.16 show that based on the medium levelized electricity cost, nuclear electricity is not cost-effective in comparison with thermal electricity generation in Iran.

5.6.1 Environmental effects

The share of CO_2 emissions by the Iranian power plant sector was about 29% of the total emissions in the country in 2010 (Ministry of Energy, 2012). Other major sources are domestic, transportation and industry with about 25%, 23% and 17% respectively. Even if Iran could construct 20,000 MW nuclear power plants by 2025, emissions in this sector in comparison with the current power plant mix will decrease by 26%. This value will be equivalent to a decrease of only about 6% of the total emissions in the country at that time. Therefore, emissions control should be taken into consideration in all sectors. Moreover, if emissions mitigation is the case, coal-fired power plants should not be constructed as they have the highest emission factors among all fossil fuel types. In addition, although Iran may gain by decreasing emissions by doing some projects, such as Joint Implementation (JI), there are some reasons that show it is not essential for the country to encourage low emissions power plants. First of all, based on the Kyoto Protocol, which was ratified by the country in 2005, Iran has no emission limitations or reduction commitment. Second, the most critical energy-related environmental problem is air pollution in Iran's big cities (Sabetghadam, 2006). There are many days, designated as public holidays by the government because of heavy air pollution. In winter 2007, air pollution killed 3,600 people during a month in Tehran, Iran's capital (Terra daily, 2007). This disaster occurred mainly, due to transportation activities and domestic fossil fuel consumption for heating. The share of power plant emissions in this problem were low, therefore, no one can deny the significant priority to resolve this lethal environmental problem by amendment of the transport and domestic sectors rather than by decreasing emissions in the power plants. In addition, NPPs are usually constructed near water resources for high efficiency at sea level and their need for a huge amount of water for use or desalination. All the big cities in Iran that have an air pollution problem are far from these locations, and, therefore, the construction of NPP would not help to decrease their air pollution problems.

There are some points about the environmental effect of NPP that should be considered. First, in considering the life cycle emissions, nuclear power is less but not a zero emissions power plant. Although they have no emissions during operation, some indirectly related activities, that use fossil fuel contribute to emissions. For example, activities during the construction, fuel fabrication from mining, uranium enrichment, transmission, used fuel repository during plant life time, and also power plant decomposition, all produce emissions (Fleming, 2007). Second, there are other pollution problems related to nuclear activities such as radioactivity in mines or in the fabrication process or from the fuel used, which will be active for thousands of years. This is a grave threat to health and to the environment and should be an important part of any nuclear development plan. According to (Hamed, 2011) nuclear energy also depends on water resources and increases the environmental degradation cost, especially for the central area and Persian Gulf coast parts of the country. Last, but not least, the recent incidents at Japan's Fukushima NPP in March 2011 have clearly demonstrated that more should be done to strengthen safety and ensure reliability, especially for a developing country such as Iran which is well-known for its long history of earthquake activity.

Many studies have been conducted to find methods for emissions abatement by improving technology. For instance, Holttinen studied the effect of wind energy on CO_2 abatement in the Nordic countries. This study showed that if coal-fired power plants were replaced by wind turbines, it could reduce CO_2 emissions by more than 0.6 kg/kWh (Holttinen et al., 2004). Romeo showed that Spain could reduce CO_2 emissions by up to 90% by 2050 in an efficiency scenario with carbon capture and storage (CCS) and renewable energies. Therefore, the development of CCS projects in Spain is essential in order to maintain economic development without increasing CO_2 emissions and as an action response to Kyoto protocol targets (Romeo et al., 2009). The use of renewable energy could reduce the share of coal power plants from 44% to 39%, as well as decrease the cumulative emissions of CO_2 by 8%, SO_2 by 3%, and NO_x by 4% in Vietnam (Nguyen et al., 2009). In addition, renewable energy could help avoid installing 4,400 MW of fossil fuel generating capacity, conserve domestic coal, and decrease coal and gases imports and improve energy security. The influence of different types of power generation technologies, especially the potential role of natural gas combined cycle and nuclear power plants on CO_2 emissions in Shanghai, China were discussed by (Gnansounou et al., 2004).

Iran could also apply many techniques to decrease emissions in the country and has high potential to decrease the amount of GHG emissions by up to 31% by 2021 (National Climate Change Office, 2003). In the power plant sector, although NPP helps decrease emissions, it is not the only choice and there are many other effective policies. For example, using the more combined cycle type by substitution of the gas turbines, avoiding construction of the high emissions coal-fired type and also switching the fuel from liquid petroleum (e.g., fuel oil and diesel) to low carbon fossil fuel (natural gas) as demonstrated in this study, will decrease emissions. Here are some other improvement policies for emissions mitigation in selected sectors (Shafie-pour, 2004):

- Power plant sector:
  - Enhancing power plant efficiency.
  - Using smart technologies for transmission and distribution.
  - Decreasing transmission and distribution losses.
  - Using carbon capture and storage technique (CCS).
  - Decarbonisation or desulfurization of fuels or flue gases.
- Industry sector:
  - Reduction of fugitive emissions at refineries.
  - Sulfur content reduction of middle distillates (fuel oil and diesel).
  - Reduction of flaring.
- Transportation sector:
  - Maintenance and inspection of vehicles based on emissions standard.
  - Scrapping of outmoded vehicles.
  - Enhancing public transport.

- Domestic and commercial sector:
  - Increasing the use of renewable sources of energy.
  - Demand side management program.
  - Standardizing and labeling for appliances.

In terms of environmental issues, especially for emissions reduction, although NPP and renewable energies are advised, developing them is not considered urgent for Iran, because it has considerable potential to decrease emissions in all sectors, which can be done easily and cheaply.

5.6.2 Energy demand

There are many indicators that show that the energy industry in Iran is unsustainable, and that the government should conduct some proper and rational energy policies to correct it in both the near-term and long-term. For example, the high growth rate of energy consumption due to over US$ 50 billion subsidies in all energy sectors, including electricity sector, and about 22% electricity loss in transmission and distribution (A. R. Karbassi et al., 2007; Khosroshahi et al., 2009; Ministry of Energy, 2009c). Due to cheap prices of all energy carriers, population growth and enhanced life standards, the final energy consumption has increased more than 7% annually, and electricity production has risen 10% yearly in the last two decades (IAEA, 2009). As shown in Figure 2-3 to Figure 2-5, the growth rate of energy consumption is higher than energy production. It is undeniable that if this trend continues Iran will not be able to export energy as the major revenue of the government in near future. To correct this trend the government eliminated energy subsidies in December 2010 (CNN, 2010). By doing so, it hopes that rising fuel prices will lead to more efficient use and finally decrease the annual rate of consumption growth in the future.

Like any other energy sector, electricity demand has greatly increased in Iran. Electricity usage has increased by over eleven-times over the past 30 years, and nominal capacity has increased by the equivalent of 1,552 MW annually, and reached 56,181 MW in 2009. If this trend continues, Iran must construct 4,200 MW each year to answer the demand.

All other sectors in the country also consume energy irrationally, sometimes higher than the world average. For example, the fossil fuel consumption in the domestic sector is almost equal to the power plant sector as shown in Figure 2-6 and Figure 2-7. The amounts of each type of fossil fuel consumption in this sector in 2009 were 75.5 Mboe, 296.6 Mboe and 0.1 Mboe for petroleum, natural gas and coal respectively. These large amounts of fossil fuel consumption which were mostly used for water or space heating, are due to low energy prices, old technologies for most energy consuming devices and lack of enthusiasm in using latest technologies in building construction. There are many cost-effective suggestions that do not need a huge amount of investment or advanced technologies, which can help control or rationalize the energy consumption trend without decreasing the country's GDP, for instance, Iran has good potential to use solar energy using simple technology, such as solar water heating instead of gas water heaters. By doing this, most of the fuel requirements of water heating in residential buildings could be eliminated. Another suggestion is applying stricter supervision of optimal energy efficiency in buildings, which is already ratified, and could help to improve this trend.

Based on Figure 2-8, there are similar problems in the power plant sector, which are depicted by its energy flow. It shows that 65.3% of the primary energy was wasted as heat and the total Iranian power plant efficiency is about 34.7%. This efficiency is about 7% less than OECD countries or about 3% less than the world average (Maruyama et al., 2009). Iran could increase the efficiency in the power plants by changing low efficiency thermal types to more efficient types such as the combined cycle, or using combined heat and power (CHP) technology. Another 7.2% of primary energy is lost in transmission and distribution networks and finally only 27.5% is consumed by the end users. The transmission and distribution networks lost or wasted about 21% of electricity generated. This huge loss, which was only about 7% in 1994, increased due to the lack of investment in the transmission and distribution network with a simultaneous development of power plant capacities (Ministry of Energy, 2011). Clearly, investment in optimizing transmission and distribution networks, is not only a high priority, but is also more cost-effective than the construction of new power plants. Wasting energy and low efficiency is not exclusive to the power plant sector. These problems and irrational use of energy also occur in most other sectors. Some studies show that the potential for energy saving in the transportation and industry sectors are about 45% and 35%, respectively (A.R. Karbassi et al., 2005). According to (Supersberger, 2009), until 2050, a 50% increase in efficiency in the power plant sector is possible on the generation side and 60% on the consumption side.

In terms of energy demand, despite the launching of the Bushehr NPP in 2012, at that time the share of the nuclear capacity and generation in the power plant sector would be about 2% and 3% respectively. This is equivalent to about 0.3% in the total country’s energy demand, which only uses electricity and no other type of energy carriers. Therefore, nuclear power plants are neither the sole solution for electricity demand nor for energy consumption in the country.

Iran can improve the electricity sector and increase sustainability by power plant improvements and technological advances in the transmission and distribution in order to reduce its losses. This will improve energy efficiency and help to postpone investment of the new power plants that are in most cases fossil fuel based. Clearly, this action is more cost-effective than developing new power plants. For example, the reduction of 3% of the 22% total loss is almost equivalent to the electricity generation in 1,000 MW based-load steam turbine or coal-fired power plants.

5.6.3 Energy security

In most countries, energy security is diversified to decrease dependency on a single source and the guarantee of fuel supplies in the long-term. These definitions for Iran (and probably some petroleum-rich countries) are not applicable, largely because of the huge fossil fuel resources, and, hence, reduced concern about such issues. Despite, Iran being the second in rank for natural gas and fourth for oil reserves, there are still some issues that jeopardize the energy security of the country.

Dependency on crude oil export

Its economic dependency on crude oil exports constitutes one of the main threats to the energy security for Iran. Keeping oil exports is vital for many countries, which is why it is encouraged by fossil fuel importers; also two wars in the Persian Gulf region have occurred to save energy exports. However, for Iran, this dependency has many disadvantages. First, receiving an easy income by exporting raw materials in the last century resulted in the lack of infrastructural development in other income sectors such as industrial, tourism, agricultural and commercial. Moreover, due to the current political situation arising from the nuclear fuel cycle, an oil export boycott will halt the country's economy, especially, when other petroleum rich nations increase their production to counter the absence of Iranian petroleum in the energy market (AsrIran, 2011b; Reuters, 2011). Furthermore, higher levels of exportation mean more exploitation, which lead to the quicker depletion of resources. Dependency on crude oil exports have also increased the military and security budget of the country to keep oil exports safe in a region of high conflict.

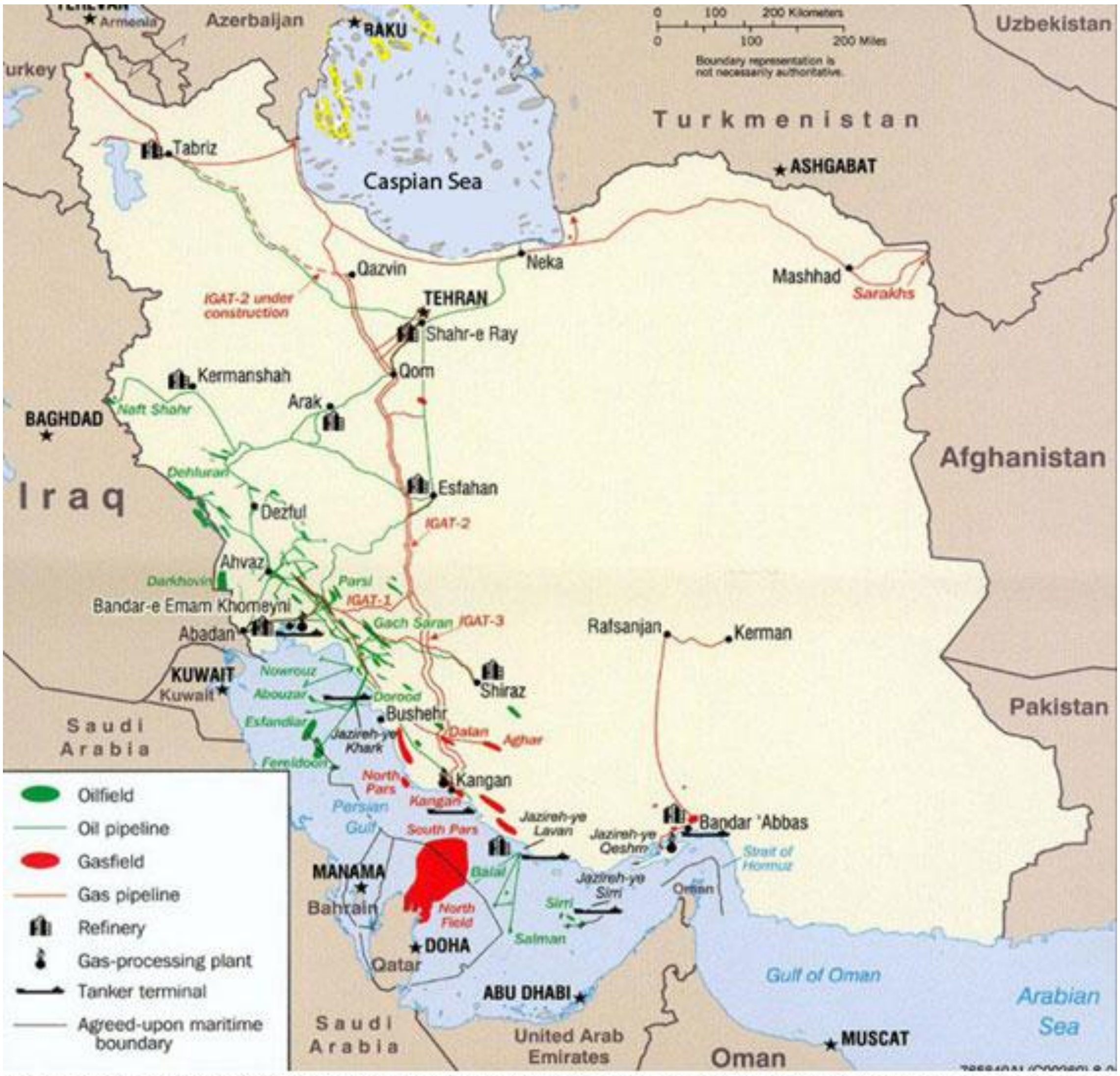
To avoid these possible problems, Iran must decrease its dependency on crude oil exports and develop other sectors and prepare for competition with other countries to export products and provide services. This policy has many benefits for the country such as coping with 10% unemployment, decreasing vulnerability to fluctuating oil prices and serious universal sanctions. Iran has the ability to develop other sources of income such as a highly educated labor source, deep ancient civilization, location in geopolitical region and four-season climate to develop agriculture sector, while using oil to support economic growth. Clearly, income from services or product exports instead of crude oil will conserve natural resources for the future. Therefore, the attitude for the crude oil income must be reformed. The income from crude oil exports should not be considered as revenue, but as selling natural wealth. Oil must be acknowledged as a strategic product because it is not renewable and there is not any substitution or alternative for it. In fact, if Iran replaces crude oil revenue with other incomes, it will have energy security for a longer period than many other countries.

High growth energy consumption

The second threat to energy security in Iran is energy consumption from high growth, largely due to huge subsidies for all energy products such as gasoline, natural gas as well as electric power. For instance, based on aging and energy-inefficient vehicles in the transportation sector, gasoline consumption has increased rapidly. In addition, due to less investment in refinery capacity, the country is not able to produce enough gasoline. Consequently, imports of gasoline have increased each year and reached almost $4 billion in 2007. Moreover, increasing energy consumption will cause limitations to the export of energy, fund wastage as well as earlier source depletion. As shown in Figure 2-3, if this trend continues it is predictable that there will not be any extra energy for export in the next decade, and that the country would have to import some part of its energy needs in later decades. Some conservation and energy management should be implemented to control the growth of demand to sustain oil resources for future use. Energy efficiency is the main key to decrease the rate of energy consumption in all sectors and help the energy security of the country. This could be done by certain policies, such as strict standards, energy price reform, social awareness and using taxation.

Common resource management

The third threat to energy security is mismanagement of energy resources. As shown in Figure 5-1, Iran has considerable common natural gas and oil resources offshore and onshore, from the Caspian Sea to the Persian Gulf and from Iraq to Turkmenistan (Rasad online, 2011), (Ministry of Energy, 2011). Iran has 28 common oil and gas resources within its neighborhood, for which extraction from 18 of them has not commenced. Iran has 15 resources in the Persian Gulf, which is common with its neighborhood (MehrNews Agency, 2011). For instance, extraction from the world's biggest natural gas field in the Persian Gulf started in late 2000, however, the developmental lag in this field has resulted in less exploitation than Qatar, which began in 1990. Although international forces and lack of cooperation were also effective, Iran should concentrate and invest more in these resources, which will be depleted even if it does not use them. For the countries that do not have common energy resources, investing in nuclear energy to diversify their energy basket and decrease dependency on energy import is rational, but for Iran not using these resources and funding other energy alternatives, such as nuclear, will not fulfill the aim of keeping fossil-fuel resources for future generations.



Source: Iran country profile 2004, Key petroleum sector facilities. U.S. CIA (PCL map collection)

Figure 5-1. Iranian oil and natural gas resources

Energy squander

The first evidence of energy squander in the country is the huge amount of energy wasted in flared gases. Although many projects to collect these gases and decrease the losses in the energy sector are in progress, about 40 million cubic meters of natural gas is burned off every day without being used. This rate shows a 3.5% growth for 2010 in comparison with 2009. The rate of this wastage in Iran is higher than the Middle East average and is four times the North American average (Qodsdaily, 2011; D. Wood, 2007). There are also some energy wastage problems in other sectors. For example, 9.6% of energy is lost in the petrochemical industry, which is double the world average of 5% and four times that of advanced petrochemical industries. This wastage is equivalent to 57 million barrels of oil per year. In addition, 10% of natural gas is lost, which is equivalent to about $3 billion per year in pipelines or in compressor stations, due to worn-out equipment. Obviously, the investment to control and utilize some of the wastage in the power sector is more cost-effective than even renewable energy (T. W. Wood et al., 2007) (Iranian Students' News Agency, 2010).

Political conflict

Political conflicts with the West have caused some difficulties for the country's energy sector. For example, there are problems in obtaining up to date technology, including enhanced recovery methods to stop the natural decline of oil production, which is estimated at 24%, as compared to the world average of 35%. This value in some countries is 48% and, in Norway, it is 65% (Bina, 2009; Khabaronline.ir, 2011). In the natural gas section, its projects for the development of PNG or LNG face many problems because of the political pressures and limitations or the requirements for significant foreign investment. One noteworthy example is the exporting of 150 million cubic meters of natural gas per day to India and Pakistan by pipeline, which was suggested about two decades ago but has not been finalized yet. As shown in Figure 5-2, other routes have been suggested and supported that bypass Iran without compromising the oil and gas exports to the international market (AsrIran, 2011a). For example, a natural gas pipeline from Turkmenistan to Pakistan and India via Afghanistan or also another pipeline which will transfer Caspian Sea oil to Europe nominated Baku, Tbilisi, and the Ceyhan pipeline. Although, currently, Iran is exporting natural gas to Turkey, it seems unlikely to extend this pipeline to be able to export natural gas to Europe. Not only, because of pressure from the West, but also because Europe is the traditional market of Russia's natural gas, and this country will be totally reluctant to have a competitor. These examples show that diplomatic efforts and international cooperation have great roles to expand Iranian energy customers around the world.

Sources: U.S. Energy Information Administration, Iran Analysis
http://www.thedossier.info/maps_charts.htm
http://guerillas-without-guns.blogspot.com/

Figure 5-2. Natural gas routes in the region

In conclusion, in terms of energy security, nuclear energy is not a rational choice for Iran. First, limited uranium resources will force Iran to seek a supplier on the world market, especially if Iran wants to construct 20,000 MW of NPPs. Therefore, this limitation will lead to some kind of dependency on foreign raw materials and will impact on the energy security of the country. Accurate analyses should be done in terms of the approved amount of Iranian uranium mines or ability to use its share abroad, to attain nuclear fuel independence (Reuters, 2010). However, there are some solutions for this concern. For example, the IAEA recently approved a global nuclear fuel bank, which aims at providing an alternative to those countries, such as Iran, which seek to produce their own nuclear fuel. There is also uncertainty about fuel fabrication costs in the country, as the direct and indirect costs of fuel enrichment are probably expensive and buying nuclear fuel is cheaper than producing. In addition, the high capital cost for NPP construction has caused another difficulty for the country, which has limited funds earned by crude oil exports. Investment in nuclear energy has led to the unfledged development of other important energy industries as well as a significant shortage of capital resources available for other projects. This is evident in the oil and gas sector, where, Iran's oil production has remained stagnant and will likely not increase due to insufficient investment and certain international limitations in developing oil fields.

Chapter 6 :

Conclusion and recommendations

The first objective of the thesis was to show a clear view of power sector development in last five decades. It describes and shows that there has been a high growth rate of electricity consumption in the country. The majority in share and capacity of power plants are fossil-fuel based. This share always was increasing, which increased from 67% to 86% and by new power plant composition will be decrease to 60% in 2025. The per capita electricity consumption was increased about 9.3% annually. The historical power capacity in the past forty years used to predict the power sector capacity in the future. The analysis shows that if this trend is to continue, the increase in electricity consumption is expected to be around 10% in the upcoming years. Accordingly, the total capacity is estimated to be about 124,000 MW in 2025, which is equal to an annual increase of 5.1%. This growth is equivalent to the construction of a 4,000 MW power plant each year. The results also show that in the new power plant composition, which government plans to increase variety from six to ten types and construct enough NPPs to be capable of supplying 20,000 MW, in various parts of the country, the consumption of natural gas will increase by 47% and diesel by 50%. In addition, coal consumption in coal-fired power plants will reach 10,826 ktons. In the second scenario where the same composition of power plants as in 2009 is assumed, all types of fuel consumption will increase by 130%, 106% and 69% for natural gas, diesel and fuel oil respectively.

In the second step to investigate the environmental effect of power plants, the pattern of emissions in the past 42 years was calculated and described. This showed that thermal power generators that use fossil fuels and play an important role in the country's power sector, are one of the major sources of emissions in the country. The results show that the best types of thermal power plant with regard to air pollution are the combined cycle, gas turbine and steam turbine, respectively. The hydropower plants are the cleanest energy source, since they have no emissions during operation. However, the study shows that these plants are unstable and can only be used as a supplementary supply because of the unreliability of water resources. Iran also has considerable potential for generating electricity from non-hydro renewable energy resources such as wind and solar. The development of these resources provides more diverse energy resources besides the dominant fossil fuels. In addition, it helps to meet the growing energy demand while addressing environmental concerns and sustainability issues; however, the amount of electricity generated from these resources is still under 0.1%. Therefore, based on data analyses, Iran has to cover the required new capacities by launching thermal power plants. The future power sector composition predicted based on the government plans. The government wants to change the structure of the power industry with lower share of fossil fuel base plants. In reality, because of the technical, economical or lack of fuel supply as well as other factors, the power sector of the country may develop differently. In this study, two other alternative scenarios were considered to understand the condition of fuel consumption and emissions in the future. This study indicates that if the power plant composition does not change the CO_2 emissions in 2025 will be 252 Mtons and SO_2, NO_x and CO emissions will increase to 72%, 119% and 126%, respectively in comparison to the respective amounts in 2009. In the new composition, by using more hydropower, renewable sources and 20,000 MW nuclear power plants, the share of the thermal power plants of the total capacity will decrease and the CO_2 emissions in 2025 will decrease 26% in comparison with the current composition. Although based on the Kyoto Protocol, there is no commitment for the country for emissions mitigation and Iran has some vital air pollution problems in the big cities, it is also possible to achieve more emissions reductions with gradual conversion of liquid fuel to natural gas, as described in the alternative scenario and by increasing the contribution of the combined cycle as a more efficient type of thermal power plant. It is found that by substitution of liquid petroleum fuels by natural gas in the new composition, Iran can decrease the emissions of CO_2 by 6%, SO_2 by 55% and NO_x by 13%. The withdrawing of coal-fired power plants and substituting them with combined cycles can also decrease the CO_2 emissions by another 9% in the future. Meanwhile, many of the other environmental problems of nuclear activities, such as nuclear radiation from uranium mining and NPP decomposition, must be considered by policy makers.

Although Iran has the second largest reserves of natural gas and the fourth largest crude oil resources in the world, it faces great challenges in securing the energy sector. In spite of the huge amount of petroleum income in the past decades, the present policy not only seriously affects the country's economic independence, but has also resulted in less development in other income sectors. The high dependency on crude oil exports, abnormal growth in energy consumption with low efficient in all sectors are other threats to the energy security in the country. Another Iranian energy security threat is low extraction share in common oil and gas resources in comparison with its neighborhoods. Not using these resources and funding other energy alternatives will not fulfill the aim of keeping these resources for future generations. Another major energy security threats such as political conflict and high energy squander described in the thesis. These all show that Iran's energy industry is unfavorable and this trend cannot continue for long time. Although for increasing energy security, the government plans to increase power plant diversity by using new types such as nuclear, coal and more renewable energies, the most important action is to reform the inefficient oil and gas consumption in all sectors, especially in nonproductive sectors such as domestic. Therefore, adopting a comprehensive policy package in the short-, medium- and long-term is essential for achieving a stable and sustainable energy supply in the future.

In the next step, the electricity price generated in different types of power plant is calculated. The calculation has been done based on major costs including capital cost, operation and maintenance and fuel cost for Iranian situations such as local fuel price, interest rate and capacity factors. The results show that the best base-load power plants are combined cycle, steam turbine, geothermal, coal-fired and nuclear respectively. For peak-load power plants, the foremost types are gas turbine and hydropower. The results also show that in the current circumstances, nuclear power does not generate cheap electricity for Iran. The price might be comparable in the future if Iran connected to the international natural gas market, decreased the country's inflation rate, achieved better international cooperation and solved the obstacles presented by sanctions.

The final objective of the thesis was to investigate the effect of NPP construction on energy sustainability in Iran. Nowadays there is a serious conflict between Iranian government and UNSC and the West about the country's nuclear activities, which caused applying heavy sanctions. So the country's atmosphere is not normal to make a decision about this technology only based on the scientifically analyses or even in the view of the public opinion. Although in many countries economic analysis or even public opinion have the major weights for making decision, in Iran other factors especially political have higher influence on this issue now. If this situation changed, researchers can do some more researches including finding public opinions around nuclear safety and also environmental risk of this type of power plant and the results can be added to other analyses have been done in this thesis. For more accurate economic analyses, an advance methodology including many other factors, must be taken into account. The factors such as financial parameter's variation, quantifying emission's costs and non-tangible parameters like risk of radioactive radiation and environmental threats. Iran's situation is different from most countries, and, therefore, its energy sustainability strategies and road map should be geared accordingly. For example, to answer the around 10% annual increase in electricity consumption, neither nuclear nor fossil fuel based power plants can meet these needs. Fortunately, Iran has a great potential for energy conservation to control and answer the demand. Decreasing 22% of electricity loss and increasing the efficiency of power plants by 34% are two high priority actions that can be done. At this time, nuclear energy cannot solve the country's energy structure weakness, and, furthermore, causes more difficulty for energy security by the increase in lateral costs, as well as the lack of financial funding and international cooperation in other energy sectors. Moreover, choosing to invest heavily in nuclear technology instead of accelerating the development of Iran's valuable oil and gas resources has led to the limited ability to produce oil and gas, and refining of petroleum products.

In conclusion, nuclear energy is useful for diversifying the types of power plant and presents some lateral benefits to industry, medicine and agriculture. It may help the energy security in many countries by enabling them to be independent or less dependent on foreign fossil fuels. Nuclear development may also be economically attractive for generating cheap electricity in certain countries that are financially stable, have a low discount rate, high energy demand growth, scarce alternative sources, and where there is a priority for energy supply security or compulsive regulation to the greenhouse gas reduction. Iran has rich oil and gas reserves and there is not concern about energy supply to require the use of nuclear energy to decrease such concerns. For Iran, even if it's nuclear activities assumed peaceful, nuclear electricity, because of direct access to low-cost fossil fuels is not cost competitive. Not only because there are other types of electricity generators that are cheaper but also because of the lack of attention and investment in the urgent and important actions required for energy sustainability. In terms of energy sustainability and security in Iran, there are high opportunities for energy security and many more effective and cost efficient ways than increasing extraction from non-renewable resources or development of nuclear power plants. Although the government's effort to keep the country's right for uranium enrichment is appreciable, the construction of more nuclear power plants in Iran is not recommended, and concentration on other alternatives will create greater energy security, job potential, environmental and economic benefits, and maintain resources for the future as well as engender political stability. Some high priority energy policies for Iran's energy sustainability are suggested below. These suggestions have even higher priority than developing renewable energy sources which is usually suggested.

- Diversifying the economy by developing other income sectors such as industry, tourism, and agriculture.
- Development of petroleum products and LNG technology to be replaced with crude oil exports and expand country's energy market.
- Pay more attention to extraction of oil and natural gas from common resources.
- Applying energy efficiency policies in all sectors to decrease high energy wastage.
- Decreasing 20% transmission and distribution network losses.
- Developing mechanisms for conserving energy such as unused flared gases.
- Decreasing tension in international relations and increasing two-way collaboration.
- Reduction in the share of coal-fired power plants as the worst fossil fuel based power plant in term of emission or using techniques to diminish the harmful effects of coal consumption.
- Use of more combined cycles for higher efficiency in thermal power plants.
- Substitution of liquid fuels with natural gas as a major fuel and arrange its supply to most thermal power plants throughout the year.

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Appendix A

Table A - 1. Nominal capacity (MW) for all types of power plants from 1967 to 2009

Year	Steam turbine	Gas turbine & combined cycle	Diesel engine	Hydro power	Wind energy	Total
1967	343	84	198	309	0	934
1968	351	98	250	309	0	1,008
1969	437	128	286	462	0	1,313
1970	434	135	310	517	0	1,396
1971	746	135	316	800	0	1,997
1972	746	172	372	804	0	2,094
1973	1,359	241	390	804	0	2,794
1974	1,587	410	414	804	0	3,215
1975	1,576	610	459	804	0	3,449

Table A-1. continued. Nominal capacity (MW) for all types of power plants from 1967 to 2009

Year	Steam turbine	* Gas turbine & Combined cycle		Diesel engine	Hydro power	Wind energy	Total
1976	1,722	658		505	804	0	3,689
1977	1,719	1,507		541	1,804	0	5,571
1978	1,719	2,887		614	1,804	0	7,024
1979	2,476	2,936		705	1,804	0	7,921
1980	3,983	3,058		783	1,804	0	9,628
1981	4,423	3,175		830	1,804	0	10,232
1982	4,423	3,201		880	1,804	0	10,308
1983	5,045	3,150		923	1,804	0	10,922
1984	5,445	3,271		899	1,804	0	11,419
1985	6,285	3,309		971	1,804	0	12,369
1986	6,855	3,438		891	1,827	0	13,011
1987	7,155	3,492		837	1,827	0	13,311
1988	7,475	3,489		803	1,914	0	13,681
1989	8,086	3,600		803	1,953	0	14,442
1990	8,086	3,940		824	1,953	0	14,803
1991	8,086	3,940		869	1,953	0	14,848
1992	8,710	4,794		856	1,953	0	16,313
1993	9,513	5,934		812	1,953	0	18,212
1994	10,742	6,960		758	1,953	0	20,413
1995	11,557	7,746		658	1,953	0	21,914
1996	11,621	8,168		662	1,969	0	22,420
1997	11,685	8,896		677	1,999	0	23,257
1998	12,400	9,422		616	1,999	0	24,437
1999	13,102	9,530		574	1,999	0	25,205
2000	14,126	6,770	3,760	533	1,999	0	27,188
2001	14,776	7,565	4,060	533	1,999	11	28,944
2002	14,840	6,857	6,290	490	3,028	12	31,518
2003	14,904	7,663	6,832	493	4,420	16	34,328
2004	15,229	9,710	6,832	493	5,012	25	37,301
2005	15,577	12,050	6,832	493	6,043	37	41,032
2006	15,553	14,862	7,836	418	6,572	47	45,288
2007	15,598	15,433	10,479	418	7,422	63	49,413
2008	15,598	18,077	11,117	418	7,672	63	52,945
2009	15,704	18,593	13,664	425	7,704	91	56,181

* Since 2000 data of gas turbine and combined cycle types have been separated.

Table A - 2. Electricity generation (GWh) for all types of power plants from 1967 to 2009

Year	Steam turbine	Gas turbine & combined cycle	Diesel engine	Hydro power	Wind energy	Total
1967	732	56	396	658	0	1,842
1968	1,088	77	411	855	0	2,431
1969	1,336	85	440	1,336	0	3,197
1970	1,978	155	452	1,671	0	4,256
1971	2,097	194	520	2,679	0	5,490
1972	2,513	265	564	3,528	0	6,870
1973	5,374	541	567	2,842	0	9,324
1974	6,545	688	511	3,421	0	11,165
1975	7,785	955	593	3,445	0	12,778
1976	8,455	1,122	659	3,975	0	14,211
1977	8,203	2,558	781	4,213	0	15,755
1978	6,316	3,928	893	6,249	0	17,386
1979	7,769	5,327	926	5,419	0	19,441
1980	8,197	5,088	976	5,620	0	19,881
1981	9,174	5,883	1,120	6,229	0	22,406
1982	12,562	6,141	1,173	6,447	0	26,323
1983	16,296	6,826	1,184	6,203	0	30,509
1984	18,309	8,780	1,255	5,750	0	34,094
1985	20,200	9,570	1,400	5,550	0	36,720
1986	22,860	7,160	1,508	7,517	0	39,045
1987	25,360	7,305	1,499	8,390	0	42,554
1988	26,968	8,146	1,350	7,311	0	43,775
1989	33,056	6,974	1,173	7,522	0	48,725
1990	38,836	8,723	1,254	6,083	0	54,896
1991	41,947	9,463	1,244	7,056	0	59,710
1992	42,362	10,866	1,224	9,530	0	63,982
1993	48,166	12,419	927	9,823	0	71,335
1994	53,376	15,402	863	7,445	0	77,086
1995	55,901	16,145	723	7,275	0	80,044
1996	62,364	15,475	610	7,376	0	85,825
1997	65,628	19,298	476	6,908	0	92,310

Table A - 2, continued. Electricity generation (GWh) for all types of power plants from 1967 to 2009

Year	Steam turbine	* Gas turbine	Combined cycle	Diesel engine	Hydro power	Wind energy	Total
1998	63,988	26,486		373	7,015	0	97,862
1999	70,689	31,156		419	4,943	0	107,207
2000	80,710	20,865	12,855	361	3,650	0	118,441
2001	83,510	20,344	17,899	328	5,057	31	127,169
2002	84,260	17,531	27,586	356	8,050	31	137,815
2003	87,670	17,697	32,895	290	11,094	30	149,676
2004	90,716	24,979	36,250	252	10,627	47	162,871
2005	93,383	32,129	36,194	212	16,085	69	178,072
2006	92,481	41,235	40,343	220	18,169	86	192,534
2007	94,228	37,604	53,796	225	17,987	141	203,981
2008	97,201	54,911	57,015	204	4,753	196	214,280
2009	95,771	53,846	64,142	124	7,232	229	221,344

* Since 2000 data of gas turbine and combined cycle types have been separated.

Table A - 3. Exchange electricity between Iran and neighboring countries (GWh)

Year	Export	Import	Exchange
1993	195	0	195
1994	197	0	197
1995	157	0	157
1996	384	0	384
1997	522	0	522
1998	622	144	478
1999	1,125	340	785
2000	1,003	326	677
2001	1,049	745	304
2002	799	977	-178
2003	919	1,489	-570
2004	1,837	2,170	-333
2005	2,760	2,084	676
2006	2,774	2,541	233
2007	2,520	1,842	678
2008	3,875	1,684	2,191
2009	6,152	2,068	4,084

Table A - 4. Population of Iran for selected years between 1956 and 2009

Year	Population
1956	18,954,703
1966	25,788,722
1976	33,708,744
1986	49,445,010
1991	55,837,163
1996	60,055,488
1997	61,070,425
1998	62,102,514
1999	63,152,047
2000	64,219,318
2001	65,301,307
2002	66,300,418
2003	67,314,813
2004	68,344,729
2005	69,390,404
2006	70,495,782
2007	71,553,218
2008	72,626,517
2009	73,715,914

Table A - 5. Total fossil fuel consumption for power plants from 1967 to 1978

Year	Diesel (*Ml*)	Fuel oil (*Ml*)	Natural gas (Mm^3)
1967	136	311	13
1968	118	420	33
1969	128	496	21
1970	165	672	22
1971	166	597	163
1972	192	514	346
1973	317	899	723
1974	399	846	944
1975	405	1,283	1,077
1976	500	1,454	1,116
1977	990	1,145	1,533
1978	1,472	1,015	1,380

Table A - 6. Composition of fuel consumption in power plants from 1979 to 1997

Year	Fuel type	Steam turbine	Gas turbine & combined cycle	Diesel engine	Total
1979	Natural gas (*Mm*^{3})	1,130	1,205	-	2,335
	Diesel (*Ml*)	27	1,097	273	1,398
	Fuel oil (*Ml*)	1,058	-	4	1,064
1980	Natural gas (*Mm*^{3})	775	1,503	-	2,278
	Diesel (*Ml*)	29	663	291	983
	Fuel oil (*Ml*)	1,473	-	-	1,473
1981	Natural gas (*Mm*^{3})	610	1,750	-	2,360
	Diesel (*Ml*)	12	606	330	948
	Fuel oil (*Ml*)	1,901	-	-	1,901
1982	Natural gas (*Mm*^{3})	1,314	1,862	-	3,177
	Diesel (*Ml*)	14	655	341	1,010
	Fuel oil (*Ml*)	1,947	-	-	1,947
1983	Natural gas (*Mm*^{3})	1,748	1,873	-	3,621
	Diesel (*Ml*)	37	886	357	1,280
	Fuel oil (*Ml*)	2,618	-	-	2,618
1984	Natural gas (*Mm*^{3})	1,672	2,213	-	3,885
	Diesel (*Ml*)	27	1,222	373	1,622
	Fuel oil (*Ml*)	3,183	-	-	3,183
1985	Natural gas (*Mm*^{3})	1,740	2,252	-	3,992
	Diesel (*Ml*)	32	1,754	406	2,192
	Fuel oil (*Ml*)	3,568	-	-	3,568
1986	Natural gas (*Mm*^{3})	1,939	1,916	-	3,856
	Diesel (*Ml*)	58	1,152	431	1,641
	Fuel oil (*Ml*)	4,150	-	-	4,150
1987	Natural gas (*Mm*^{3})	3,183	2,268	-	5,451
	Diesel (*Ml*)	91	952	437	1,480
	Fuel oil (*Ml*)	3,559	-	-	3,559
1988	Natural gas (*Mm*^{3})	3,271	2,459	-	5,730
	Diesel (*Ml*)	86	1,042	389	1,517
	Fuel oil (*Ml*)	3,839	-	-	3,839
1989	Natural gas (*Mm*^{3})	4,666	2,197	-	6,863
	Diesel (*Ml*)	61	855	344	1,259
	Fuel oil (*Ml*)	4,101	-	-	4,101
1990	Natural gas (*Mm*^{3})	5,454	2,862	-	8,316
	Diesel (*Ml*)	34	751	358	1,143
	Fuel oil (*Ml*)	4,809	-	-	4,809

Table A-6, continued. Composition of fuel consumption in power plants from 1979 to 1997

Year	Fuel type	Steam turbine	Gas turbine & combined cycle	Diesel engine	Total
1991	Natural gas (*Mm*^{3})	5,870	3,230	-	9,099
	Diesel (*Ml*)	23	585	357	965
	Fuel oil (*Ml*)	5,144	-	-	5,144
1992	Natural gas (*Mm*^{3})	6,283	3,575	-	9,858
	Diesel (*Ml*)	29	717	357	1,103
	Fuel oil (*Ml*)	4,853	-	-	4,853
1993	Natural gas (*Mm*^{3})	6,948	4,553	-	11,501
	Diesel (*Ml*)	22	782	268	1,072
	Fuel oil (*Ml*)	5,786	-	-	5,786
1994	Natural gas (*Mm*^{3})	7,767	4,774	-	12,541
	Diesel (*Ml*)	30	867	253	1,150
	Fuel oil (*Ml*)	5,887	-	-	5,887
1995	Natural gas (*Mm*^{3})	7,862	4,730	-	12,593
	Diesel (*Ml*)	45	1,093	211	1,349
	Fuel oil (*Ml*)	6,700	-	-	6,700
1996	Natural gas (*Mm*^{3})	8,640	4,801	-	13,443
	Diesel (*Ml*)	32	801	180	1,014
	Fuel oil (*Ml*)	7,446	-	-	7,446
1997	Natural gas (*Mm*^{3})	9,894	5,707	-	15,604
	Diesel (*Ml*)	36	983	141	1,160
	Fuel oil (*Ml*)	7,038	-	-	7,038

Table A - 7. Composition of fuel consumption in power plants from 1998 to 2009

Year	Fuel type	Steam turbine	Gas turbine	Combined cycle	Diesel engine	Total
1998	Natural gas (Mm^3)	11,685	2,573	5,145	-	19,403
	Diesel (*Ml*)	55	418	209	113	796
	Fuel oil (*Ml*)	4,870	-	-	-	4,870
1999	Natural gas (Mm^3)	12,311	2,338	6,585	-	21,234
	Diesel (*Ml*)	28	662	246	137	1,073
	Fuel oil (*Ml*)	5,946	-	-	-	5,946
2000	Natural gas (Mm^3)	13,640	2,817	6,426	-	22,883
	Diesel (*Ml*)	48	727	400	107	1,283
	Fuel oil (*Ml*)	6,492	-	-	-	6,492
2001	Natural gas (Mm^3)	15,059	6,342	3,600	-	25,001
	Diesel (*Ml*)	79	1,122	366	100	1,667
	Fuel oil (*Ml*)	6,799	-	-	-	6,799
2002	Natural gas (Mm^3)	15,930	5,410	6,258	-	27,598
	Diesel (*Ml*)	74	1,138	331	109	1,652
	Fuel oil (*Ml*)	6,275	-	-	-	6,275
2003	Natural gas (Mm^3)	17,893	5,532	6,843	-	30,268
	Diesel (*Ml*)	44	948	361	86	1,439
	Fuel oil (*Ml*)	4,938	-	-	-	4,938
2004	Natural gas (Mm^3)	18,127	7,372	7,183	-	32,682
	Diesel (*Ml*)	47	1,456	608	78	2,189
	Fuel oil (*Ml*)	5,736	-	-	-	5,736
2005	Natural gas (Mm^3)	18,343	9,506	7,204	-	35,053
	Diesel (*Ml*)	64	1,862	660	62	2,648
	Fuel oil (*Ml*)	6,329	-	-	-	6,329
2006	Natural gas (Mm^3)	16,539	10,968	7,732	-	35,239
	Diesel (*Ml*)	90	3,344	1,203	65	4,702
	Fuel oil (*Ml*)	7,587	-	-	-	7,587
2007	Natural gas (Mm^3)	16,164	10,435	10,377	-	36,976
	Diesel (*Ml*)	132	2,271	2,088	66	4,557
	Fuel oil (*Ml*)	8,435	-	-	-	8,435
2008	Natural gas (Mm^3)	16,792	15262	11,357	-	43,411
	Diesel (*Ml*)	70	2970	1,299	59	4,398
	Fuel oil (*Ml*)	8,911	-	-	-	8,911
2009	Natural gas (Mm^3)	15,726	14,737	12,841	-	43,304
	Diesel (*Ml*)	49	3,037	1,812	37	4,935
	Fuel oil (*Ml*)	9,541	-	-	-	9,541