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Iranian Electrical Production and Consumption System Modeling: A Theoretical Study for Investigation of Possible Scenarios

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Abstract

Concerns related to climate change and security of energy supply is pushing various countries to make strategic energy planning decisions. In this regard, energy system modelling is an appropriate method to find out the utilization of current declining non-renewable energy resources and other possible scenarios. Consequently, it is available to consider various aspects of energy system decisions and some probable alternatives. This paper investigates different scenarios for Iran's electrical energy system applied in LEAP. Two different demand forecasting methods are used and the effects of applying four supply- side scenarios on CO_2 emissions from power sector are finally compared.

Keywords: Energy system modeling, CO2 emission, LEAP, Energy planning.

1. Introduction

In attaining a sustainable growth in economic, social and industrial areas, energy demand and supply studies play a key role. On the one hand, construction of energy-generating industries is a time-consuming and also an expensive issue. On the other hand, the capability to supply the required energy has political and social importance for governments. Besides this, there is no doubt that ignoring energy issues, such as by failing to provide a suitable way to meet energy demand causes many serious and complex challenges in all economic and social areas. On the other hand, energy demand and supply studies provide appropriate foundations for rational decision making.

An accurate utilization of energy resources and appropriate decision making in order to divide these resources up according to different types of demand are essential issues, which guarantee sustainable development and also help protect precious energy resources. In accordance with these facts, energy system modelling is a method which helps energy policy makers to achieve their goals. Among common energy system models, LEAP is one of the most flexible and popular models, which is used by many different countries around the world [1].

Energy resource planning is an important issue that supports developing countries which have availability of natural resources. Iran is a country which has more than one-fifth of the world's natural gas reserves and more than 9 % of its crude oil reserves; although it uses more than half of these resources for domestic requirements, it seems that it suffers more from a lack of supply side than demand side planning. However, in recent years, a quick growth in energy demand in Iran and some unfavourable political and social effects on its energy system have led to many challenges, such as concerns about future energy security. These challenges also bring different environmental problems.

Electricity generation is one of the most important primary energy-consuming areas, which consumes about 27% of the entire natural gas supplied by the country. Thermal power plants, which have the biggest share in electricity generation, are divided into three main types: steam cycle, gas turbine and combined cycle. The fuels used by these power plants consist of natural gas, diesel and residual fuel oil, and each technology utilizes a main and an auxiliary fuel. The average rate of their efficiency is 38.1 %, and according to the type of fuel used, each technology releases some emissions. Figure1illustrates the electrical energy flow in Iran as a reference energy system (RES) and Table1 shows the electricity production, consumption, import and export in comparison with the total energy of the country [2].

Table.1.
Iranian Electricity Sector Information (2012) [2]

Energy Resource	Production	consumption	Import	Export
Total (MBOE)	2219.1	1058.6	48.8	653.2
Electricity (TWh)	254.3	201.6	3.9	11
Electricity Share (%)	0.07	0.11	0.49	0.01

The main purpose of the following research is the implementation of an Iranian electrical energy system model using LEAP software considering all of the generation, transmission, distribution and consumption details, in order to analyse some possible scenarios which forecast the energy system's technological and environmental behaviour. Because of the impossibility of catching up with renewable energy profits in a short time, the scenarios are evaluated based on current technologies. There are planned changes to the share of the power sector's fuels, such as building combined cycle power plants (which are used as a gas turbine type) and improving the efficiency of them.

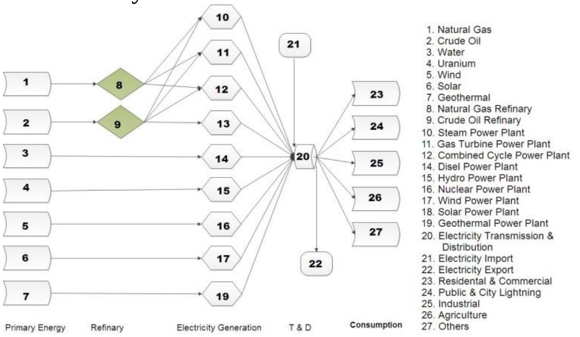

Fig. 1. Iranian Electrical Energy Flow as a Reference Energy System (RES) [2]

1. Literature Review

Recently, several researches have been focused on supply side management (SSM) and policies around the world. In 2007, Rachmatullah et al. devised a long-term electricity supply plan for the electricity system in Indonesia [3]. It was found that: (a) the scenario planning method could save up to US$3.5 billion over a 15-year Period. (b) Introducing integrated coal gasification combined cycle and advanced gas combined cycle units would reduce greenhouse gas emissions from the system by 15% compared to a reference scenario over a15-year planning timeframe. The abatement cost was found to be US$4 per ton of CO_2. In 2009, Daniel et al. surveyed various electricity generating options to meet the energy needs of various demand sectors [4]. Energy saving techniques and hybrid technologies were considered and various scenarios were developed by assessing the contribution of renewable energy technologies over the planning period. The role of renewable energy technologies and of energy saving measures was also evaluated by imposing suitable constraints on CO_2 emissions and primary energy sources exploitation. In 2010, Hiremath et al. used goal-programming method in order to analyze the decentralized energy planning through bottom-up approach in India [5]. Different scenarios were considered at four decentralized scales for the year 2005 and were developed and analyzed for the year 2020. Decentralized bio energy system for producing biogas and electricity, using local biomass resources, were shown to promote development compared to other renewable energises. In 2011, Tao et al. used LEAP model to simulate China' slow-carbon economic development level in 2050 [6]. It was indicated that China has achieved a considerable decrease in its CO_2 emissions mainly due to improved energy intensity. Fuel switching and renewable energy penetration also exhibited positive effect to the CO_2 decrease. In 2011, Yophy et al. provide an overview of energy supply and demand in Taiwan, and used the LEAP model to compare future energy demand and supply patterns, as well as greenhouse gas emissions, for several alternative scenarios of energy policy and energy sector evolution [7]. Results of scenarios featuring ‘‘business-as-usual’’ policies, aggressive energy-efficiency improvement policies, and on-schedule retirement of Taiwan's three existing nuclear plants were compared, along with sensitivity cases exploring the impacts of lower economic growth assumptions. In 2011, Wang et al. surveyed the latest development of energy production, energy consumption and energy strategic planning and policies in China [8]. They also described the analysis, carried out by the authors as part of the Asian Energy Security project using the Long-range Energy Alternatives Planning (LEAP) modeling tool, of the impacts of implementing new and expected energy and environmental policies. In 2011, Skoufa and Tamaschke investigated the issues of institutional and technological change using the social cost perspective and focused on the imperatives of greenhouse gas emission reductions in two Australian states [9]. The carbon pricing in the power generation sector which is dominated by coal-and gas-fired power plants, was considered up to AU$40/t CO_2.

Then the merit order for dispatch changes was introduced. Deducing that a carbon dioxide price creates much stronger investment incentives for wind than for nuclear or photovoltaic technologies, in 2011, Castilo and Linn analyzed an electricity system model of Texas, then, a detailed simulation model was used to consider a hypothetical carbon dioxide price of \$10–\$50 per metric ton for the Electric Reliability Council of Texas market [10]. It was demonstrated that the composition of the existing generation system may cause electricity prices to increase by different amounts over time when a carbon dioxide price was imposed. The simulations also showed that, for the range of prices considered, the increase in electricity prices was positively correlated with output from a typical wind unit, but the correlation was much weaker for nuclear and photovoltaic. In 2011, Kahrl et al. examined the challenges to China's transition to a low carbon electricity system, in which renewable energy would play a significant role [11]. They discussed that the China's electricity system lacked the flexibility in planning, operations, and pricing to respond to conflicting pressures from demand growth, rising costs, and environmental mandates in a way that simultaneously maintains reliability, decarbonizes the system, and kept prices within acceptable bounds. It was concluded that a greater flexibility crucially requires the ability to more systematically and transparently manage and allocate costs. In 2011, Mondal et al. examined the impacts of CO_2 emission reduction target and carbon tax on future technologies selection and energy use in Bangladesh power sector during 2005–2035 [12]. The results of some policies on CO_2 emission constraints showed that the introduction of the CO_2 emission reduction targets and carbon taxes directly affect the shift of technologies from high carbon content fossil-based to low carbon content fossil-based and clean renewable energy-based technologies compared to the base scenario. Achieving the total energy generation costs and GHG emissions of four scenarios, in 2012, Bautista used the quantitative approach to analyze the present and future situation of the Venezuelan power generation sector [13]. It was shown that Venezuela had all the required resources to achieve sustainable development in the power generation sector. It was also proved that an energy efficiency improvement was the easiest path to reduce GHG emissions. In 2013, Park et al. analyzed the energy, environmental and economic influences of three electricity scenarios in Korea by 2050 [14]. It was found that: (a) Although the greenhouse gas emissions from electricity generation in 2050 in two scenarios were similar with current emissions, emissions in the third scenario were about 80% lower than emissions in 2008. (b) While nuclear and coal-fired power plants accounted for most of the electricity generated in two scenarios, the third scenario projected that renewable energy would generate the most electricity in 2050. In 2014, Kale and Pohekar forecasted electricity demand for the target year 2030, for the state of Maharashtra (India) [15]. Three scenarios were generated which include business as usual, energy conservation and renewable energy. It was shown that the estimated values of greenhouse gas for first and second scenarios, in the year 2030, were 245.2 percent and 152.4 percent more than the base year and for the third one, it was 46.2 percent less. Exploring various potential future scenarios and the associated impacts on the system marginal cost, global warming potential, and resource diversity index, in 2014, McPherson and Karney analyzed the current status of power generation in Panama [16]. Four scenarios were developed and analyzed and for each scenario, the composition of the electricity generation profile, system marginal cost, global warming potential, and resource diversity were predicted. Some studies have also been carried out on Iranian energy sector, which have mostly focused on demand side management (DSM). In 1974, de Carmoy described the energy and development as two facets of a coherent long-range policy [17]. She discussed the requirement of an energy policy for Iran for the first time and analyzed the principles specific goals of the long-range policies. In 2005, Hosseini et al. assessed the integrated solar combined cycle power plants, technically and economically [18]. It was demonstrated that these technologies were able to saves 59 million \$ in fuel consumption and reduces about 2.4 million ton in CO_2 emission during 30 years operating period. In 2006, Ardehali tried to identify problems and difficulties encountered in the social–economic infrastructure as related to rural energy development [19]. The analysis showed that while there are numerous non-renewable and renewable energy resources available, problems such as cultural barriers and lack of appropriate mentality about energy impede the much-needed development in the rural areas of country. In 2006, Davoudpour and Ahadi examined the potential for greenhouse gases mitigation in household sector of Iran [20]. This research revealed that if the energy carriers' price was increased to border price and energy efficiency programs were implemented, they would stimulate carriers' demand and CO_2 emissions growth rate have been decreased to 4.94% and 3.1%. Developing a 25-year least cost plan for energy management in the Iranian building sub-sector, in 2007, Sadegh Zadeh investigated an energy flow optimization from the point where the final energy was delivered to consumers, until the useful energy and energy services point [21]. A proposed energy efficiency plan resulted in 27%, 54% and 10% saving in energy consumption, energy cost and investment cost, respectively. In 2008, Sadeghi and Hosseini concerned an integrated energy plan for Iranian transportation sector using a techno-economic approach with the optimal consumption pattern of fuels focusing on vehicle technologies within the next 25 years [22]. Their scenario declined fuel consumption by about 14% totally, and total discounted cost of transportation system declined from 806.20 to 691.74 billion dollars (14%) during the time horizon. In 2011, Azadi and Yarmohammad analyzed Iran's oil export capacity and the factors affecting it as a major source to respond to the increasing domestic energy demand [23]. The future of oil export in Iran was predicted in three optimistic, reference, and pessimistic scenarios and domestic and foreign investment and the history of buyback contracts and their undeniable role in development of Iranian oil and gas projects were discussed. In 2012, Amirnekooei et al. developed a reference energy system and forecasted the energy consumption for a 25 year period in Iran [24]. They also examined the effects of several demand and supply side management strategies on resource depletion and environmental emissions. The results showed that applying four different scenarios up to year 2035 resulted in crude oil and natural gas savings equivalent to 1.67, 1.24, 1.86, and 3.22 times Iran total primary crude oil and natural gas supply in 2009.

2. Methodology

The present research is limited to the Iranian electrical energy system, consisting of power generation, transmission, distribution and consumption, and detailed attention to technologies, fuels and air pollutants. The latest energy balance sheet for Iran, which was released in 2012, determined the data references and the scenarios were designed for the period 2013-2030. Scenarios are internally consistent narratives of how the energy system might evolve over time in a particular socio-economic setting and under a particular set of policy conditions.

To calculate energy supply and demand and greenhouse gas (GHG) emission of the energy sectors, the long range energy alternatives planning system (LEAP), which provides a bottom-up modelling tool as a Windows-based software system for energy and environmental policy analysis, was selected. LEAP, which was developed in 1980 in the USA and is currently maintained by the Stockholm Environment Institute, is an integrated modelling tool that can be used to track energy consumption, production, and resource extraction in all sectors of an economy. It is widely used for integrated energy planning and climate change mitigation analysis, and has been applied in hundreds of different organizations in over 190 countries [25]. Analysing the energy supply and GHG emissions at the local, national and multinational level, investigating the reduction potential of energy consumption and emissions by each demand sector, studying different changes of emissions according to the change of power generation structure or diffusion of generation technologies, analysing economic feasibilities considering the cost variation of each scenario, etc., are some of the econo-environmental applications of the method [13].

Reporting the system impacts, such as different types of electricity production and resource depletion, the model matches the energy demand with appropriate supply side technologies. The scenario manager of LEAP provides the ability to compare results of different scenarios. Additionally, LEAP applies an annual time-step, and the time horizon can extend for an unlimited number of years (typically between 20 and 50). Finally, the software shows an energy balance report which follows the standard format used by the International Energy Agency (IEA) and facilitates the ability to investigate the entered data's correctness in a short time [26].

3. Scenarios

Energy scenarios refer to a set of energy pathways that are designed to understand a particular issue. The use of scenarios to investigate alternative future developments under a set of assumed conditions has a long history. Scenarios are also the main tools used to address the complexity and uncertainty of future challenges. Energy scenarios provide a framework for exploring future energy perspectives, including various combinations of technology options and their implications[x]. Since LEAP software provides a bottom-up model for energy systems, final energy consumption should be forecasted in order to carry out supply side analysis. The present research is based on two different forecasts whose results will be compared for all designed scenarios. The first suggested method considers a mid-term average (MTA) of the previous eight years for an energy demand growth rate. This means 1.99% growth for household and commercial sectors, 7.23% for industry, 0.57% for transportation, 11.4% for agriculture and -2% for other demands per year for Iran's power sector [2].

Another method is based on regression analysis. Regression analysis is used when predicting a continuous dependent variable from a number of independent variables. In this case, the energy consumption is the dependent variable of linear regression analysis, and a comparison of two methods is illustrated in Figure2, which shows the electricity final demand in Iran up to 2030. Finally, these predictions were used to examine the effect of BAU, CCS, EIS, NGS and ALL scenarios. Some basic assumptions were considered while designing the scenarios:

- The population growth rate was estimated based on the World Bank's prediction, in which a population of 90.44 million people is forecast for Iran by 2030[27].

- The time period of the analysis spans the years 2013 to 2030, with 2012 as the baseline year.
- The aggregation of transmission and distribution (T&D) losses and power sector internal consumption were estimated to be as high as 21.97% in 2012, and were considered to remain constant until 2030 in all scenarios.

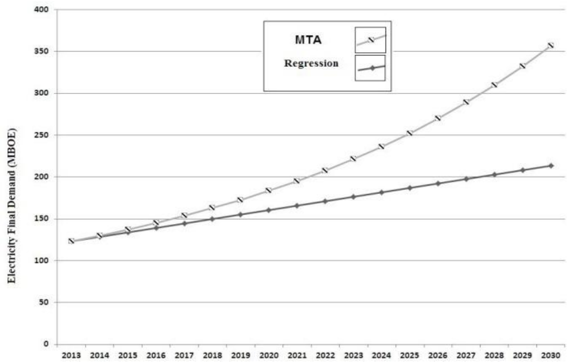

Fig. 2. Electricity Demand of Iran by 2030

A. Business as Usual (BAU)

The Business as Usual scenario continues the generation trajectory that has been observed over the past decade, based on the direction in which the selected location is heading. In this scenario, it is assumed that the development trends in the future will follow the trends set up in the past and no changes in policies will take place. In BAU, all variables and parameters in the electric system follow the past trends. These include electricity generation technologies, transmission and distribution losses, efficiencies, the percentage share in electricity generation and the fuel used.

B. Combined cycle projects scenario (CCS)

This scenario was based on a basic plan for mid-term electricity supply suggested by Iran's government. Turning gas turbine power plants into combined cycle ones means a considerable change is expected in electricity generation technologies by 2030. Gas turbine power plants, which account for about 37 % of installed capacity in the Iranian power generation sector and have an average efficiency of 29.7%, are actually parts of the combined cycle projects which are intended to be operated in combination with a steam cycle. While gas turbines emit 849.803 grams of CO2 per KW-h, they will generate electricity as combined cycles with an efficiency of 45.5% and 483.116 grams per KW-h of CO2 emission. This scenario also assumes that two-thirds of gas turbine installed capacity turns into combine cycle during the planning horizon. Some new gas turbine power plants which are being constructed will enter the power generation sector.

C. Efficiency improvement scenario (EIS)

This scenario is characterized by a plan for efficiency improvement in Iran's thermal power plants. The average efficiency of thermal power plants in Iran is 38.1%. This scenario considers an increase of 4.25% for efficiency during 17 years, which means a 0.25% improvement each year. Since the purpose of the research is to examine the technological and environmental effects of the scenarios, the economic characteristics of the plan are not considered. However, it seems to require the least capital investment of all the scenarios.

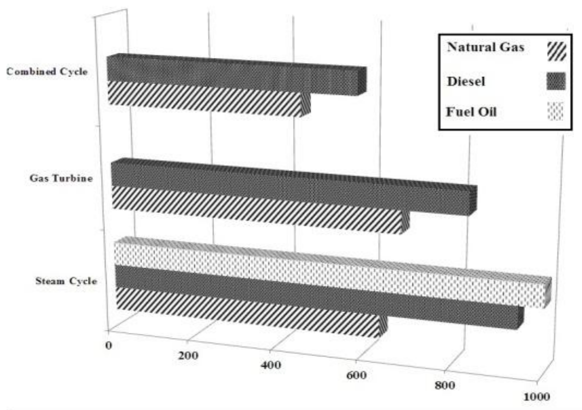

Fig. 3. CO_2 Emission from Iranian Thermal Power Plants (gram/kw-h) [2]

D. Natural gas scenario (NGS)

The Iranian power generation sector consists of three natural gas-based thermal power plants, which produce 93.3% of total required electricity of the country. Since the priority of the government is to provide natural gas for the household sector, power generation technologies have to use auxiliary fuels such as diesel and fuel oil in the winter. Undoubtedly, these fuels are environmentally more pollutant than natural gas, as illustrated in Figure3. Figure4 shows the share of different fuels in the operation of the three mentioned technologies. In order to reflect a governmental plan to increase the natural gas production from southern resources, this scenario includes a plan to expand the share of natural gas in electricity generation. A 0.5% increase of natural gas in the fuel share is assumed for each technology during the planning time period.

4. Result and Discussion

A. CO_2 emission

In BAU, the amount of CO_2 emission during planning years is equal to 5235.8 million tons based on MTA, and 4591.7 million tons based on regression analysis (REG). Figure5 shows the difference of CO_2 emission when operating three different scenarios. Between the three mentioned scenarios, CCS is expected to reduce the rate of emission more than EIS and NGS. Its emission is equal to 371.5 million tons for MTA and 242 million tons for REG, which means decreases of 21.8 and 14.2 million tons per year for MTA and REG, respectively.

In comparison with BAU, EIS is able to release less CO_2 by 4.2% for MTA and 3.9% for REG. NGS also mitigates it by 1.2% for MTA and 1.1% for REG. Finally, operating all scenarios at the same time causes a decrease of 658.9 and 478.8 million tons of CO_2 during 17 years, which means reductions of 38.7 and 28.1 million tons each year for MTA and REG predictions, respectively.

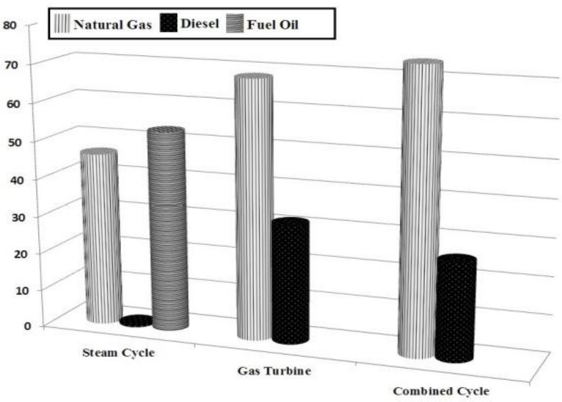

Fig. 4. Share of Different Fuels in the Operation of Thermal Power Plants (%) [2]

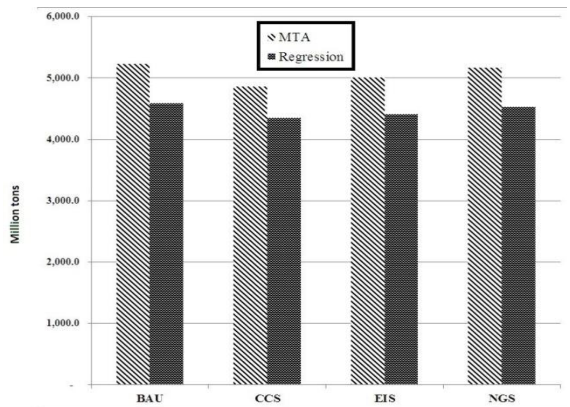

Fig. 5. CO_2 Emission from Iranian Power Sector by 2030

As it is visible in figure8, in the different types of forecasts and scenarios, different amounts of primary and secondary resources are required for the power generation sector. Operating the model by BAU, 14.8 billion barrels of oil equivalent (BOE) will be required based on MTA forecast. The amount of required resources for REG is 12.6 billion BOE.

NGS is the most energy-consuming scenario, consuming almost the same amount as BAU by 2030; however, it requires more primary and less secondary energy. CCS will need the least amount of resources, equal to 5.2% and 3.8% less than BAU for MTA and REG forecasts, respectively. These differences emanate from mitigation in primary resource consumption.

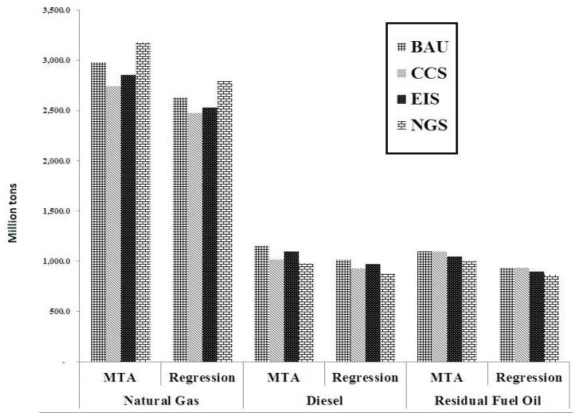

Fig. 6. CO_2 Emission from Different Fuels of Iranian Power Sector by 2030

Figure6 illustrates the share of each fuel in the described procedures, according to different forecasts and scenarios where the natural gas has the largest share among three fuels. Figure7 also divides Figure5 into various power generating technologies, among which gas turbine power plants tend to be the most pollutant.

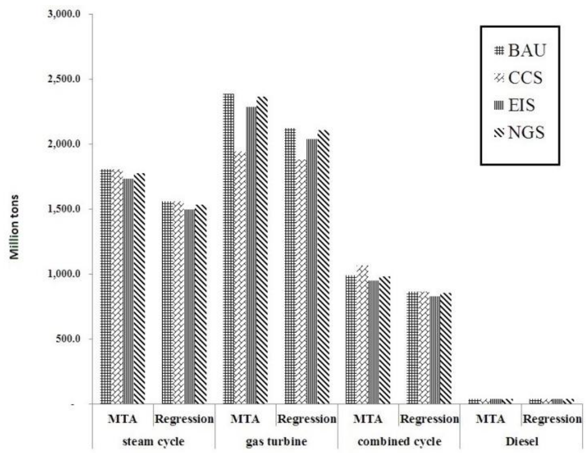

Fig. 7. CO_2 Emission from Iranian Power Sector by 2030

5. Conclusion

An overview of the Iranian power system was presented as an introduction. The importance of supply side planning was described and a reference energy system diagram presented. Different relevant studies were examined in relation to supply side and side planning of energy systems. Considering different modelling tools, LEAP was selected and the required data were adapted to the software for a mid-term study. Electrical energy final demand was predicted for each sector through two methods by 2030. It was obvious that following the current demand growth procedure required more energy in comparison with regression analysis forecasts. With the exception of BAU, which presented the same share of technologies, fuels, and constant efficiency over the 17 years, three actual scenarios based on governmental plans were designed. Operating the model according to these scenarios revealed that CCS has the greatest ability to mitigation CO_2 production by 21.8 and 14.2 million tons each year based on MTA and REG forecasts, respectively. Natural gas among the three fuels and gas turbine power plants among the four technologies were identified as the most pollutant.

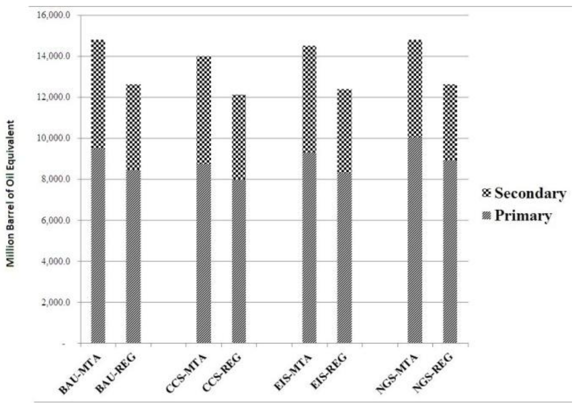

Fig. 8. Resource Requirement of Iranian Power Sector by 2030

On the other hand, NGS and CCS were shown to have the largest and the smallest resource consumptions, respectively. As a result, CCS seemed to have the largest effect on the Iranian power sector, whereby some gas turbine power plants with the efficiency of 29.7% and average CO_2 emission of 849.803 grams per kilowatt-hour are changed to combined cycles with efficiency of 45.5% and 483.116 grams per kilowatt-hour of CO_2 emission.

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