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Environmental and Economic Analysis of Scenarios for Transition to Renewable Energy in the Iranian Electricity Supply System

Abtin Ataei*, Khaled Fararian

Department of Energy Engineering, Graduate School of the Environment and Energy, Science and Research Branch, Islamic Azad University, Tehran, Iran

Abstract

Renewable energy resources are environmentally friendly and considered as a strategy for decreasing greenhouse gases (GHGs). This paper aims to model the Iran electricity supply system by using Long range Energy Alternative Planning system "LEAP" tool. For this purpose three long-term scenarios, including: reference (BL), current governmental policies (GP) and transition to renewable energies (RE) are used to analyze the effects of energy, economy and environment of each scenario on electricity supply sector until 2040.The final growth rate of electricity demand in GP scenario was less than the BL scenario and in RE scenario, it was less than the GP scenario. The structure of electricity supply system in BL and GP scenarios was approximately similar and combined cycle power plant supplied most of the electricity in these scenarios. In RE scenario by increasing the share of renewable energies in the electricity supply portfolio, 65% of the produced energy, was supplied from renewable resources. This structural change in the RE scenario is resulted in decreasing 157.5 million tons carbon dioxide equivalent of greenhouse gas (GHG) emissions compared to the BL scenario as well as 20% and 30% increase in the total production costs compared to BL and GP scenarios, respectively.

Keywords

Renewable Energy, LEAP Model, Electricity System Scenarios, GHG Emissions Reduction

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1. Introduction

With Industrial and economic development, population growth and improving the living standards, energy demand especially electricity is rising rapidly. Since by increasing the electricity consumption, greenhouse gas (GHG) emissions from electricity generation is continually increasing, adopting policies to reduce these emissions is crucial. Most of the observable increase in average global temperature since the mid-20th century is due to the increases in anthropogenic greenhouse gas concentrations [1]. GHG emissions and abrupt climate change with irreversible adverse impact on water resources, ecosystems, human health, food security and coastal settlements are only parts of the environmental consequences of fossil fuel consumption.

While global GHG emissions reached to 53.5 Gt CO_2eq per yrin 2012 [2], and Global CO_2 emissions from fossil fuel combustion and industrial processes, increased in 2013 to the new record of 35.3 billion tons Gt CO_2 [3], the energy supply sector was the largest contributor to global GHG emissions that accounts for 35 % of anthropogenic GHG emissions [4]. According to the IEA, Iran is among the first 10 largest greenhouse gas producer countries.

There are many alternatives for decreasing the GHG emissions from the energy systems while still satisfying the global demand for energy services. Some of these possible options are energy conservation and efficiency, fossil fuel

* Corresponding author
E-mail address: abtinataei@gmail.com (A. Ataei)

switching, Renewable Energy (RE), nuclear and carbon capture and storage (CCS) [5]. This paper will concentrate on the role that the deployment of RE technologies can play in the mitigation of GHG emissions from the electricity generation system.

As well as having a large potential to mitigate climate change, RE can provide wider benefits. RE may, if implemented properly, contribute to social and economic development, energy access, a secure energy supply, and reducing negative impacts on the environment and health [5].

According to the Iranian government's current plan for long term energy sector expansion, it is expected that demand for electricity will increase more than double by 2040[6].To respond to this demand and because of very low cost of fossil fuels in Iran, the current policy of electricity supply system is based on the use of natural gas instead of liquid fuels in power plants and conversion of gas power plants into combined cycles. This approach taken by the government is mainly due to the consideration on costs and paying much attention to the environmental impact of using fossil fuels.

Compared with other fossil fuels, natural gas is clean and has the least amount of contaminants. However, due to high volume of consumption, 54 % of all carbon dioxide emissions is from the natural gas that in terms of climate change issue is significant [7].Continuation of current trends in terms of power plant fuel supply, carbon dioxide emissions, in addition to high costs of investments in this sector, will become a serious challenge. In addition, the limited availability of fossil energy carriers especially in the cold season and possible increase in their prices are the most serious problems facing the industry.

In energy supply systems analysis, cost is not the only purpose and other parameters such as decreasing GHG emissions and replacing fossil fuels with renewable resources are also important and should be considered in the analysis. For this reason in the present study by using LEAP model [8] the structure of electricity supply system in Iran under transition to renewable energies scenario with the purpose of decreasing GHG emissions until the end of planning period by increasing the share of renewable technologies in electricity supply system will be planed. Additionally the effect of this change on electricity production, installed capacity of each technology, cost and GHG emissions will be studied.

A review on expansion of the country power sector during the period after 1978 shows that: the installed capacity of power facilities has increased from 7024 MW in 1978 to 70279 MW in 2013 [9]. The total Electricity generation has increased from 17,386 GWh in 1978 to 262,192 GWh in2013, which indicates the annual average growth of 8.1 % [9]. While the total primary energy supply has increased 216.7% from 69.3 to 219.6 and consequently the CO_2 emissions has increased 198.7% from 178.7 to 532.2[10]. Additionally the GDP of Iran has increased 141.6% from 101.5 in 1990 to 245.2 in 2012 [10].

The electricity generation structure in Iran has been considerably changed from 1978 to 2013. In 1978, Steam Turbines accounted for 36.33%; Gas, 22.60%; Diesel, 5.13%; Hydropower, 35.94%; Combined Cycle, 0.0% and renewable energy (non-hydro) and Nuclear, 0.0%.In 2013, Steam Turbine accounted for 34.20%; Gas, 25.19%; Combined Cycle, 33.23%; Diesel, 0.03%; Hydropower, 5.52%; renewable energy (non-hydro), 0.08% ; and Nuclear, 1.75% [9].

It is obvious that currently most of the electricity is provided by Gas Turbines, Steam and Combined Cycle power generation. The share of hydroelectric power plants was significantly decreased compared to 1978. Although potential of renewable sources of energy in Iran is high, the share of these sources in the electrical production is limited to 0.08% in 2013.

In 2012, the share of the power sector in CO_2 emissionswas31.37% and average CO_2 emissions index in the power sector was 719.468 g / kWh. The steam power plants with 53.1% of total emissions, were considered as the largest pollutants among the energy department power plants. [7]

Social costs of environmental degradation caused by the consumption of fossil energy carriers in the country, according to the World Bank and Environmental Protection Agency studies in 2012, was about 102.6 trillion Rials based on constant prices of 2002, which is equivalent to 19.6 percent of GDP in that year [7].

2. Methodology

2.1. LEAP Model

In the present study, in order to analyze the electricity system, GHG emissions and cost based on the long term scenarios, LEAP model (version 2014) [8] was used. LEAP, the Long range Energy Alternatives Planning System, is a widely-used software tool for energy policy analysis and climate change mitigation assessment developed by the Stockholm Environment Institute (SEI)[11].

The basic version of LEAP was developed by Paul Ruskin from R&D group of the Stockholm Environment Institute for integrating the energy and environment analysis of energy systems in 1980. LEAP model is a proper tool for evaluation of energy policies, establishing and policy making in energy

section and evaluating GHG emissions. This software on the basis of scenario approaches, evaluates the effects of energy sector expansion on GHG emissions and provides comprehensive information regarding cost analys is of decreasing emissions for users.

LEAP has been used for a variety of tasks including, energy forecasting, greenhouse gas mitigation analysis, integrated resource planning, production of energy master plans, and energy scenario studies. [11] Various authors have carried out studies with LEAP model. Cai et al. [12] analyzed emissions reduction potential in China's electricity sector. Giatrakos et al.[13] evaluated the electrical energy status, and examined the possibility of further penetration of sustainable energy of Crete. Jun et al [14] studied the economic and environmental influence of renewable energies on existing electricity generation market of South Korea. Park et al.[15] used LEAP model to analyzed the scenarios for the transition to renewable energy in the Korean electricity sector. Amirnekooei et al. [16] used LEAP to generate energy scenario and carried out demand and supply sides analysis for Iran. Ghanadan and Koomey[17] developed and analyzed exploratory scenarios to explore alternative energy pathways in California. Global Green Growth Institute studied energy and GHG-reduction scenarios with a bottom-up techno-economic analysis for development of green energy systems in Mongolia [18]

LEAP modeling software has been very useful for energy research and analysis in Iran. For instance, we can refer to the first report of climate change in Iran about the United Nations Framework Convention on Climate Change in 2002, estimating the demands of energy carriers until 2041, planning the production and consumption of petroleum products in 2009, specifying fuel consumption portfolio in the country in transportation section in 2009, and simulating demand and supply of energy carriers until 2035 in Iran in 2013 [19].

2.2. Data Structure

The LEAP data set is composed of key assumptions, demand, transformation and resources. The key assumption includes exogenous variables such as macro-economic indexes, demographics, and other related parameters that are used for predicting the demand data. Demand module includes different sections of energy consumer. Transformation module are used for modeling the supply section and converting energy, domestic consumption and transmission and distribution network.

Technical and economic characteristics of power plant technologies were entered to the model according to the following information: the long-term energy section expansion report in the country [20], the electrical power supply system structure plan reported by electricity and energy Macro Planning Office, Ministry of Energy of Iran [6] and renewable power generation cost report of IRENA [21] (See Table 1).

Table 1. Technical and economic characteristics of power generation technologies.

Technology	Capital cost	Fixed O&M cost	Variable O&M cost	Efficiency	Capacity credit	Maximum Availability	Life time
	$/kW	$/kW	$/kW.yr	%	%	%	year
Steam Turbine	1100	9.4	4.2	41.2	100	76	30
Gas Turbine	550	4.5	5.6	36.5	100	70	12
Reciprocating Engine DG	800	8	43.8	42.5	100	80	10
Combined Cycle	950	4.4	3.6	52.5	100	73	30
Diesel Generator	550	8	43.8	33	100	70	10
Coal Conventional	1600	64	-	35.5	100	85	30
Coal Advanced	2200	64	-	48	100	85	40
Coal Gasification	3700	148	-	49	100	80	40
Nuclear LWR	4800	92	4.4	31	100	80	40
Nuclear ALWR	5800	69	4	33	100	85	60
Fuel Cell DG	4200	-	-	57.5	100	90	5
Wind Farm	1500	48	-	100	30	30	20
Wind DG	1800	48	-	100	30	30	20
Solar PV DG	5000	50	-	100	30	30	20
Solar PV	4000	50	-	100	25	25	25
Solar CSP	5700	64	-	100	40	40	30
Geothermal	5600	84	84.5	30	100	80	30
Hydro Small	2000	14	-	100	50	50	30
Hydro Large	1500	10.8	-	100	30	20	50
Hydro Pump	2000	12.6	-	80	30	30	30
Biomass Landfill	2400	20	130	22	100	85	20
Biomass Direct Combustion	5800	580	-	30	100	80	25

According to detailed statistics of Iran's Electricity Industry [22] domestic consumption of power plants as well as transmission and distribution loses are 3.5 % and 16% respectively. In addition, transmission and distribution loses are expected to reach to 9% at the end of planning period.

The duration of 26 years from 2014 to 2040 is considered as system planning horizon. Power plants fuel composition extracted from "detailed statistics of Iran's electricity industry- production of electricity in 2013" [22]and it is offered in the Table 2.

It is supposed that compounding the use of the resources according to the existent limitations of using natural gas in the cold sessions and other conditions until end of the planning period are constant.

Table 2. Power plants fuels composition according to the statistics of 2013.

	Steam Turbine	Combined cycle	Gas Turbine
Natural Gas	31.90 %	71.10 %	69.13 %
Diesel	1.18 %	28.90 %	30.87 %
Residual Fuel Oil	66.92 %	-	-

To calculate GHG and air pollutants emissions, the Tire 1 method of the revised 1996 IPCC guideline for inventory [23] was used. The costs of energy carriers is another important parameter for supply side that in the current study is extracted from the report of electrical power supply system structure plan [6] and offered in the Table 3.

Table 3. Cost of different fuels.

Fuel	Natural gas	diesel	Residual fuel oil	coal	Nuclear	Biomass	Hydrogen
Cost	0.2 $/m3	0.435 $/lit	0.387 $/lit	10.5 $/ton	0.08 $/kWh	2.5 $/MMBtu	4 $/kg

2.3. Scenario Design

In this study, three scenarios of reference (BL), current governmental policies (GP) and transition to renewable energies (RE)were analyzed. In the reference scenario, electricity supply system is developed without any new policy.

The GP scenario is offered according to electrical power supply system structure planning in Iran reported by "Ministry of Energy of Iran, Electricity and Energy Macro Planning Office"[6].

In the GP scenario according to the "Fifth Development Plan of the Islamic Republic of Iran"[24] until 2016, 12000 Megawatts of gas power plants will be changed to combined cycle.

In the RE scenario, environmental aspect is a priority that by increasing 65% of the share of renewable power plants in the electricity supply system portfolio and developing the power plant section by using renewable technologies, this issue would be possible. In the RE scenario decreasing the GHG emissions of the power plant section at the end of planning period compared to 2013 and decreasing of dependency to fossil fuels aiming at decreasing the environmental impacts with least possible costs in electricity section are considered.

The final electricity demand growth during planning period under each scenarios is shown in the Table 4. In the GP scenario by assuming that consumption management policies are applied, the rate of energy consumption is lower than BL scenario and also the rate of energy consumption in RE scenario by assuming the efficiency improvement of electricity consumer systems is less than GP scenario.

Table 4. Finalelectricity demand growth changes during planning period.

	BL scenario	GP scenario	RE scenario
2013-2024	5 %	5 %	5 %
2025-2040	2.5 %	2.2 %	2.1 %

3. Result and Discussion

3.1. Capacity Analysis

Figs. 1, 2, 3, and Table 5 show different technologies of power plants as total installed capacity in the planning period under different scenarios.

In the reference scenario the total installed capacity was expected to increase from 71125MW in 2013 to 133783 MW in 2040. Steam turbine and gas power plants were outdated gradually and combined cycle and hydropower technologies were replaced. Coal power plant was entered to the circle as of 2016 and after that new capacity is not economical.

In the governmental policies scenario, total installed capacity in 2040 will reach to 134844MW.Capacity change compared to the reference scenario is not significant, but according to the Fifth Development Plan policies, decreasing capacity of the gas power plants occur at the beginning of the planning period, until 2016. Capacity of the steam power plants at the end of planning period reaches to less than the half of capacity in 2013. Gas turbine and pump storage technologies selection, mainly was to cover the peak load. Additionally suggesting the solar power plant in the model was imposed solely with regard to SANA constraints for building this capacity.

In the transition to renewable energies scenario the total installed capacity will reach to 214232 MW in 2040 due to increasing the share of renewable power plants with fewer accessibility factor in the model. The installed capacity of wind, hydro, and biomass power plants at the beginning of the period reaches to the maximum potential of the installable capacity in Iran, due to competitive ability of this technologies. To reach to maximum share of renewable energies (65%) in electricity supply portfolio, the model offers solar technologies.

Table 5. Power generation technologies in the form of total installed capacity.

	2013			2020			2030			2040		
Branches	**BL**	**GP**	**RE**	**BL**	**GP**	**RE**	**BL**	**GP**	**RE**	**BL**	**GP**	**RE**
Steam Turbine	15,830	15,830	15,830	14,780	12,829	13,022	14,780	11,327	9,011	12,575	6,575	5,000
Gas Turbine	24,715	24,715	24,715.	15,923	12,091	21,419	15,500	11,747	16,709	15,078	11,402	12,000
Reciprocating Engine DG	183	183	183.	223	263	463	583	583	3,023	543	583	3,023
Combined Cycle	17,850	17,850	17,850	28,160	33,690	19,704	47,360	52,890	22,352	64,640	72,090	25,000
Diesel Generator	408	408	408	413	413	408	453	458	408	453	458	408
Coal Conventional	650	650	650	650	650	650	650	650	650	650	650	650
Coal Advanced	-	-	-	-	-	-	-	-	-	-	-	-
Coal Gasification	-	-	-	-	-	-	-	-	-	-	-	-
Nuclear LWR	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020	1,020
Nuclear ALWR	-	-	-	-	-	-	-	-	-	-	-	-
Fuel Cell DG	-	-	-	0	0	0	0	0	14	0	0	24
Wind Farms	204	204	204	604	604	3,404	4,204	4,604	15,004	7,404	8,204	15,004
Wind DG	-	-	-	70	70	560	700	770	5,040	1,260	1,400	5,040
Solar PV DG	-	-	-	0	0	1	1	1	33	2	2	123
Solar PV	-	-	-	1	50	763	10	550	17,231	19	1,050	63,300
Solar CSP	-	-	-	30	30	458	300	330	10,369	570	630	38,010.
Geothermal	-	-	-	5	5	700	50	55	5,000	95	105	5,000
Hydro Small	-	-	-	150	300	1,200	1,500	1,650	2,550	2,550	2,550	2,550
Hydro Large	10,265	10,265	10,265	10,765	11,265	14,265	15,265	15,765	25,265	20,265	20,765	25,265
Hydro Pumped	-	-	-	300	600.	2,400	3,000	3,300	10,200	5,700	6,300	10,200
Biomass Landfill	-	-	-	1	1	4	5	6	164	9	10	616
Biomass Direct	-	-	-	50	50	350	500	550	2,000	950	1,050	2,000
Total	71,125	71,125	71,125	72,749	73,931	80,790	105,881	106,255	146,043	133,783	134,844	214,232

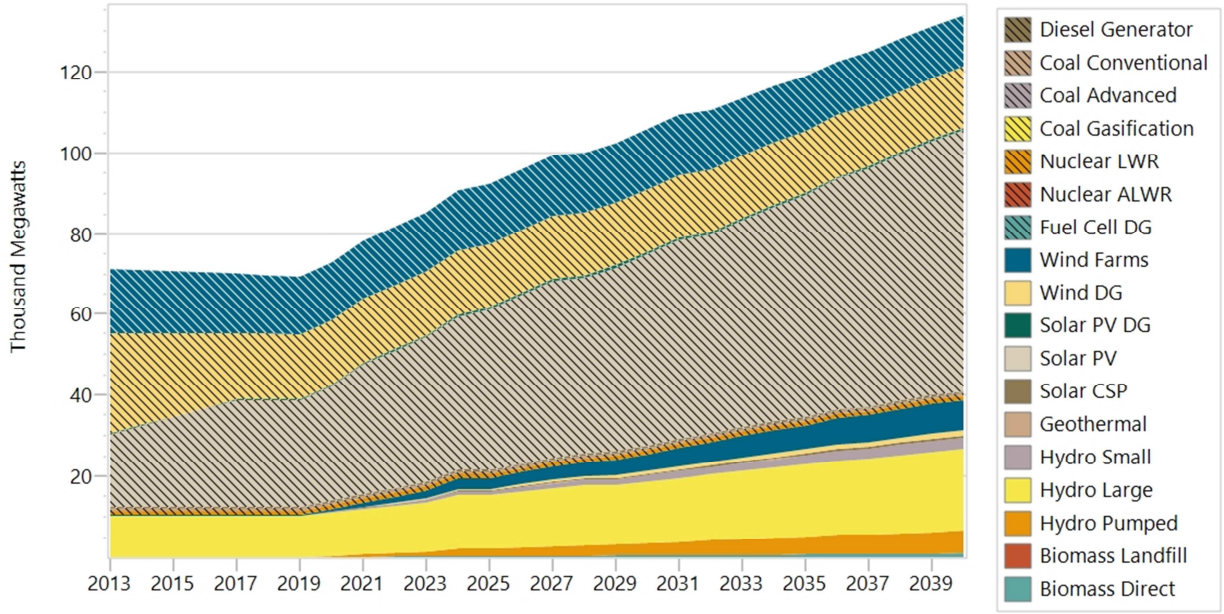

Fig. 1. Total installed capacity in the reference scenario.

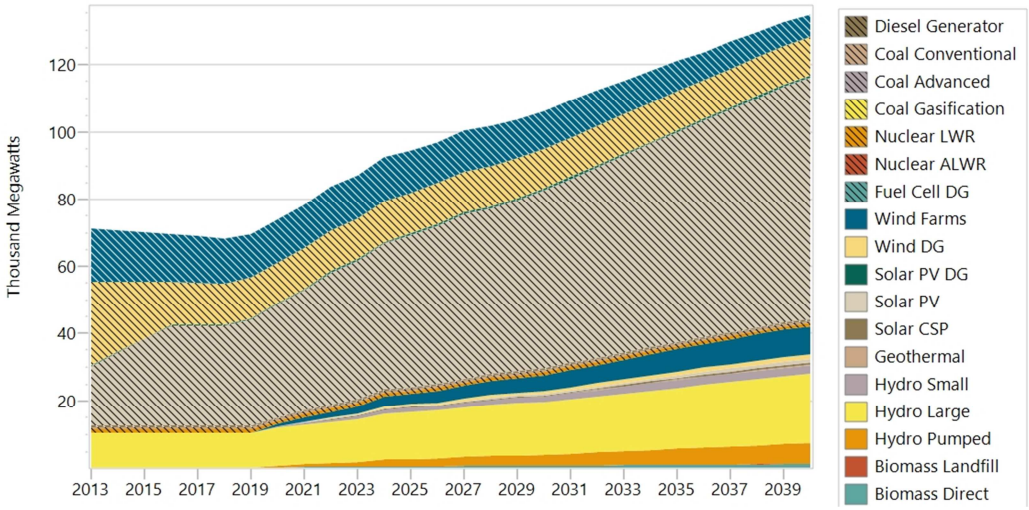

Fig. 2. Total installed capacity in the government policy scenario.

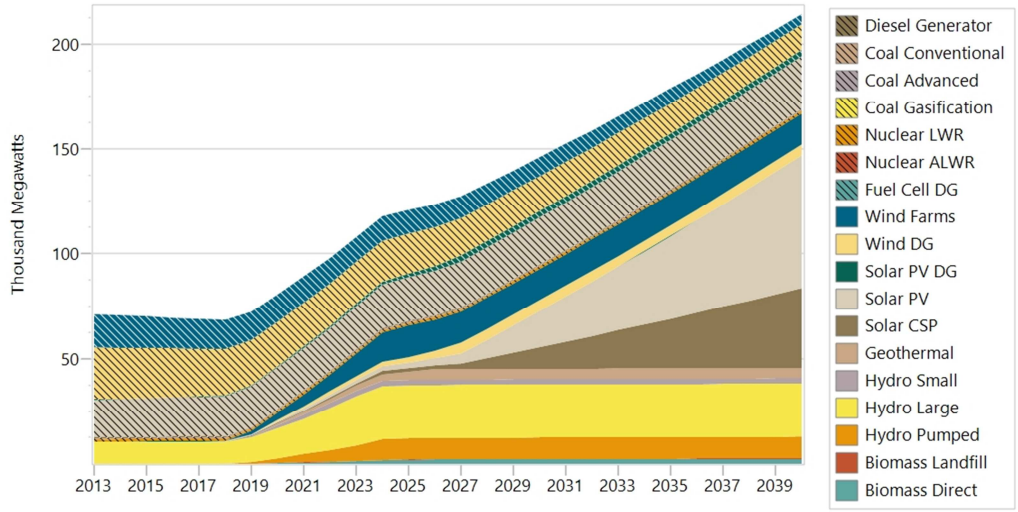

Fig. 3. Total installed capacity in the transition to renewable scenario.

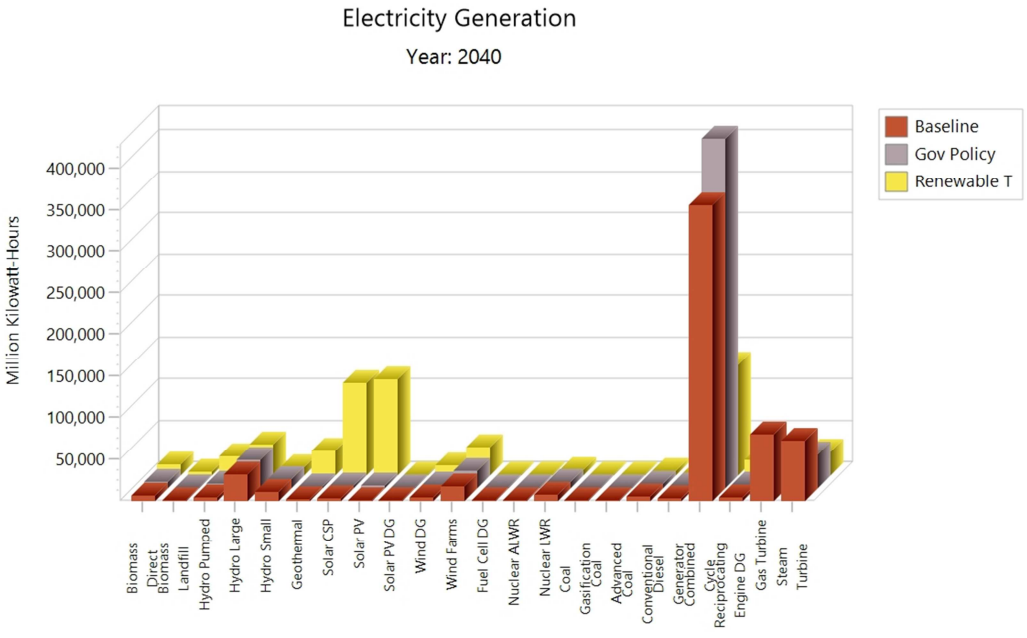

Fig. 4. Comparing generated electricity of each technology under different scenarios.

3.2. Energy Analysis

As shown in Table6, electricity generation was expected to increase from 262192GWh in 2013 to the following values by 2040: 594172GWh in the BL scenario; 579204GWh in the GP scenario; and 575452GWh in the RE scenario. In the BL scenario the major share of electricity generation at the end of the planned period generated by combined cycle, gas power plant, steam power plant, and hydro power are: 59.8%, 13.4%, 12.1%, and 7.3%respectively.

Table 6. Electricity generation of each technologies in 2040.

Branches	Baseline	Government policy	Renewable target
Steam turbine	71,953	39,919	27,560
Gas turbine	79,464	19,174	4,427
Reciprocating engine	3,271	3,726	17,540
Combined cycle	355,266	420,406	132,360
Diesel generator	2,387	2,561	2,071
Coal conventional	4,160	4,414	4,007
Coal advanced	-	-	-
Coal gasification	-	-	-
Nuclear	6,144	6,519	5,918
Fuel cell	2	2	154
Wind farms	16,723	19,662	32,645
Wind dg	2,846	3,355	10,966
Solar PV dg	4	5	268
Solar PV	36	2,097	114,772
Solar CSP	1,717	2,013	110,268
Geothermal	572	671	29,010
Hydro small	9,599	10,185	9,247
Hydro large	30,515	33,177	36,647
Hydro pumped	3,735	4,540	22,193
Biomass landfill	58	68	3,794
Biomass direct	5,722	6,710	11,604
Total	594,172	579,204	575,452

In the GP scenario the highest share of electricity supplied by combined cycle power plant is 72.6%, while the percentages for the hydro power plant, steam power plant and wind power plant are 8.3, 6.9 and 4. The share of gas power plants in GP scenario was reduced to 3.5%.

In the RE scenario solar power plant (CSP and PV) with 36.7% was the main electricity supplier and after that combined cycle power plant generated 23% of electricity. While the share of steam and gas power plants decreased to 4.8% and 0.8% respectively, the share of hydro, wind, geothermal and biomass was 11.9%, 7.6%, 5%, and 2.7% respectively.

The share of renewable power plant (non-hydro) in supplying electricity in the RE scenario was about 55% at the end of the planning period, while this share in the BL and GP scenarios was 4.7% and 6% respectively. Fig. 4 compared generated electricity by each technology considering the studied scenarios.

3.3. Cost Analysis

Cumulative total cost of production in each scenarios is calculated by the model. The total cost of production includes: capital cost, fixed O&M cost, variable O&M cost, social costs and fuel cost. In the BL, GP and RE Scenarios total cost of production was 53791, 49777, 64428 million Dollars respectively. In the RE scenarios this cost was approximately 20% more than the BL and about 30% more than the GP scenario.

Although by replacing renewable energies with fossil fuels in the RE scenario, the fuel cost and social costs decreased, due to the high expense of capital cost of renewable technologies, the amount of total cost in the RE scenario was higher. Anyway, the impacts of increasing the fuel cost or decreasing the capital cost of renewable technologies, during the planning period are not applied in the model. Fig. 5 shows the total costs of production based on each scenarios.

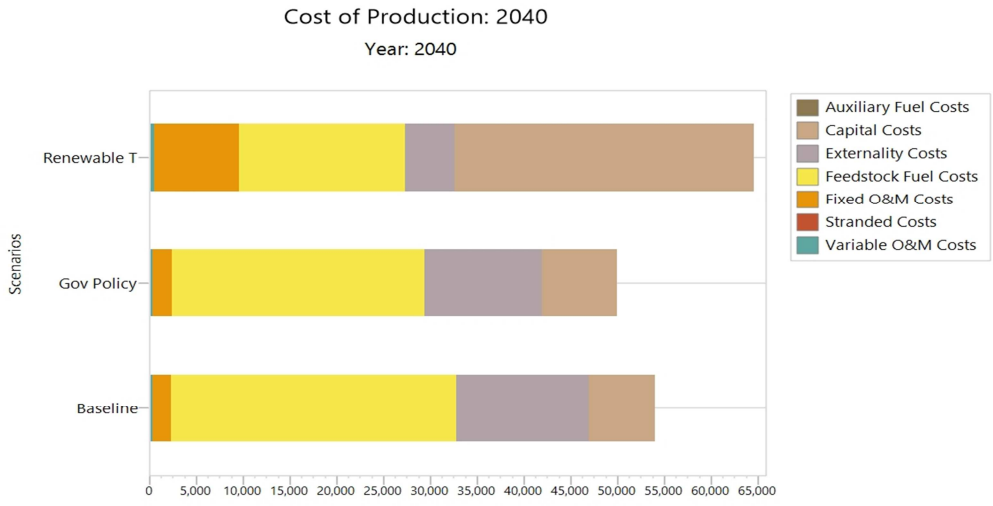

Fig. 5. Total cost of production for each scenarios.

3.4. Environment Analysis

In 2013,GHG emissions in the power section was 129.6 million tons of CO_2 equivalent and in 2040this number in the reference scenario reached to 254.2 with 96% increasing. Fig. 6 represented changes in emissions in 2040,based on each scenario compared to the reference scenario.

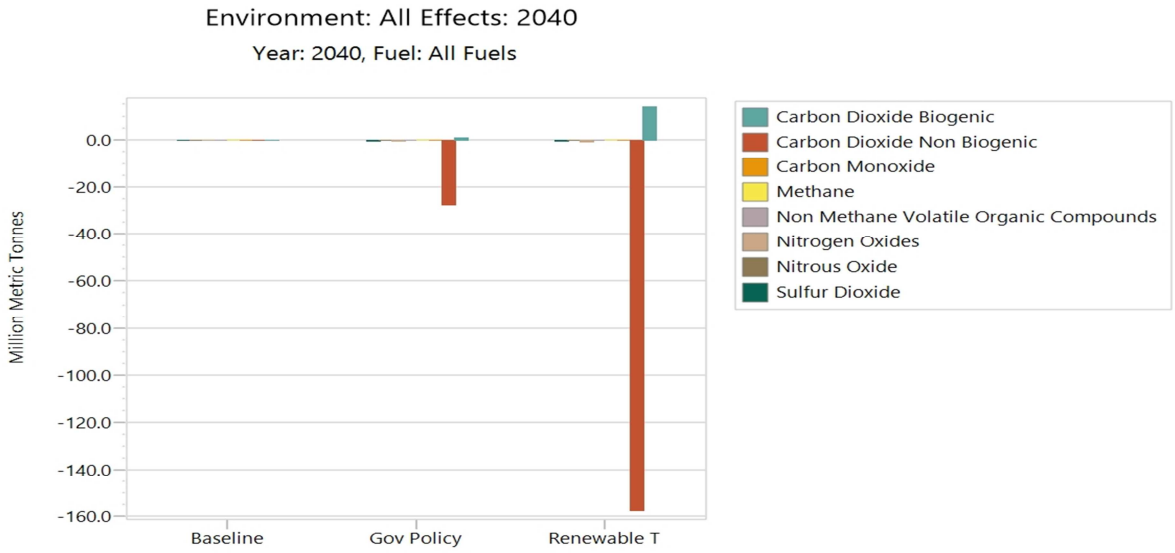

Fig. 6. Changing in GHG emissions of each scenarios in 2040 compared to the reference scenario.

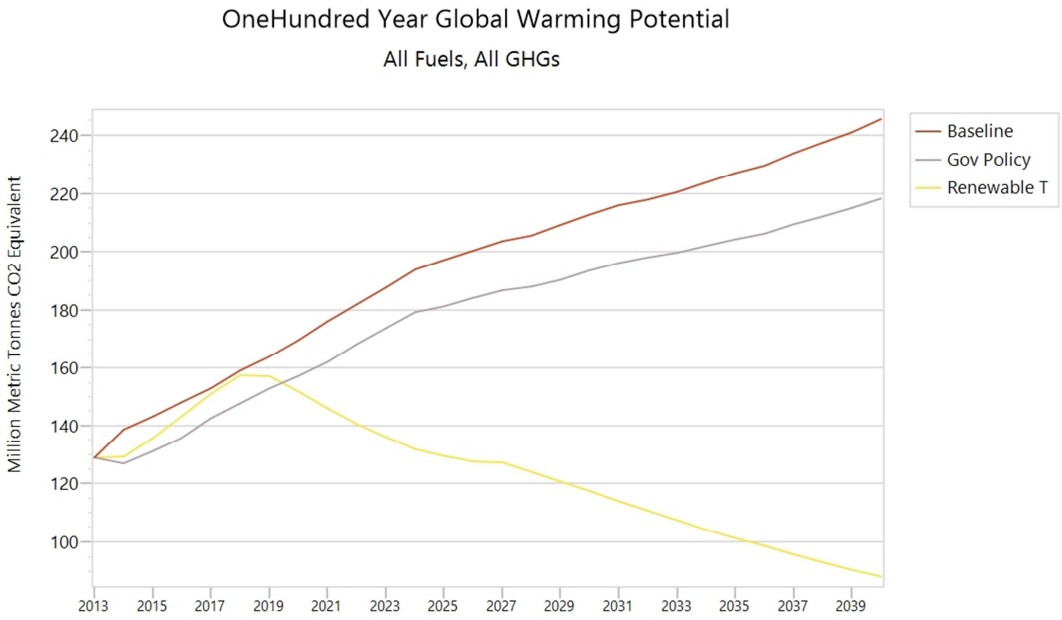

Fig. 7. One hundred year global warming potential trend in each scenario.

In the RE scenario by assuming the biomass power plant in the electricity supply system, biogenic Carbone dioxide emission increased in 2040compared to the other scenarios. Fig. 7 represented trend of one hundred year global warming potential under each scenarios, during the planning period.

4. Conclusion

The present study analyzed the energy, economic and environmental effects of scenarios of Iran electricity system, up to 2040. BL and GP Scenarios were designed on the basis of combined cycle power plants and other fossil fuels. The RE scenario was designed based on renewable energy sources. The final electricity demand growth in the GP scenario was less than the BL, because of applying consumption management policies, and in the RE scenario was less than GP due to efficiency improvement of electricity consumer systems.

Though, in BL and GP scenarios the share of gas and steam power plants in electricity supply portfolio, at the end of the panning period, according to the low efficiency of such technologies were decreased compared to combined cycle, the system totally depends on fossil fuels and combined cycle power plants was the main suppliers of electricity in such scenarios. Otherwise in RE scenario the system was not dependent on fossil fuels and most of the electricity was supplied by renewable technologies.

By increasing the share of renewable power plants in electricity supply portfolio in RE scenario,CO_2 emissions were decreased 157.5 million tons compared to the reference scenario at the end of planning period.

Being independent on fossil fuels and decreasing GHG emissions in RE scenario were affected by increasing 20%, 30% of the production costs than those of BL and GP scenarios.

This study showed that decreasing GHG emissions of electricity section, by using renewable technologies does not impose a considerable cost on the system.

In this paper, by using the basic information, three investigated scenarios have been utilized to design the sustainable structure of electricity supply system in Iran up to 2040. In the future studies it is possible to study more detailed information of changes in fuel and renewable technologies prices as influential factor. In addition, it is possible to integrate the system with electricity storage technologies and micro grids.

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