The Analysis of Environmental Policies in Electricity Generation: An Empirical Study from Yazd Regional Electricity Company in Iran

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Abstract

Environmental pollution has raised increasing concerns at both national and international levels. Among different sources of pollutions, power generation process is an important factor as it may provide one of the main sources of gas emission. Defining appropriate policies in power provision process which prevent the increasing trend of pollution maintaining the economic development is a complicated problem. In this paper, the power provision system is considered as a comprehensive dynamic model to analyze the results of different policies. The effectiveness of the model in handling the dynamism of the system and analyzing the policies is validated with a real case in province of Yazd in Iran.

Keywords
Environmental Pollutions; Power Provision System; System Dynamics; Policy Analysis.

1. Introduction
In recent years, the increasing amount of environmental pollutant shows the need for applying appropriate policies to prevent this trend. In addition, the power plants are among the main sources of environmental pollutants in different countries. As a result, making green and environment-oriented power provision policies are critical for the sustainable development. There are various researches which focused on the problem of reducing power generation pollutants in recent years [1,2,3]. In general, these studies are divided in two categories. In the first category, macro-economic analytical approaches are considered to analyze different policies [1,2,4,5]. In the second category, different methods of econometrics have been applied to comprehend the patterns of behaviour of different variables [3]. The main problem of these researches is that they have considered the environmental variables as isolated variables in power generation system. But the reality is that the environmental variables play as a part of a power provision system. This makes an analyzer to consider the effect of different variables on the environmental indices and comprehend the dynamism of the power provision system. The behavioural simulation is an appropriate approach to deal with the dynamism of different systems. The capability in dealing with the dynamism of different complex systems in addition to the high level of flexibility and accuracy in system analysis make behavioural simulation as the most favourable approach in handling complex systems. System Dynamics is one of the main techniques of behavioural simulation, which studies the relationships between variables and makes a good understanding of the considered system. Because of the complexity of energy systems with a huge number of variables, especially in developing countries, SD is a flexible technique to handle these systems. Although SD is a useful technique in energy programming, there are not many researches that considered it, especially in electricity markets. Moreover, most of the related researches have not considered all the subsystems in energy market. In other words, these researches have focused on the analysis of some parts of system such as regulating, Price and tariff, demand and so on and no comprehensive model has been created in this problem.

The most comprehensive study in this field is represented by the European Institute for Energy Researches (EIFER) which shows the application of SD for the German Electricity Market. In their SD model named ZERTISM, the effect of different policies are evaluated based on economical and environmental points of view (price and CO2 emission). For this purpose, they have considered 8 likely scenarios for German electricity market [6]. The first attempts in the application of SD in electricity energy programming is performed by Rahn [7] and Ford [8,9]. Rahn, in his first paper, used SD in the simulation of capacity provision in Canada. In another research, Turan & et al [10] used SD to analyze the demand, capacity provision, export, import and regulation subsystems of electricity supply system. Kilank & or [11] presented a SD model, focused on the role of Distributed Generation (DG) technologies and the results of different scenarios are analyzed.Qudratollah [12] represented a model for understanding the dynamics of electricity supply, resources and pollution in Pakistan. In their model named MDESRAP, 4 different scenarios including base case, environment-oriented, market-oriented and self-oriented scenarios are analyzed considering economical and environmental indices. For this purpose, the gross domestic production (GDP) and the amount of CO2 emission are considered as the appraisal criteria for a period from 2000 to 2030. As it is stated in the review of the previous researches, there was no comprehensive SD model which has been considered all the relevant variables and subsystems of electricity supply system. In this paper, a system dynamic model is represented in which all relevant subsystems of electricity system are taken into account. The result of the model is evaluated based on different environmental and also economical criterion. The effectiveness of the model in handling the dynamism of system and analyzing policies is validated with a real case in province of Yazd in Iran.

2. Iranian Electricity Market (Yazd Province)

In the electricity provision structure of Iran, there are some regional electricity companies that manage all of the electricity value chain throughout the region. Moreover, these regional companies have some subordinate companies that deal with supplying, transferring, dispatching and the other parts of electricity value chain. Up to now, all the parts of electricity value chain are exclusively handled with the government sector. Only in recent years, private sector has invested in some new power plants, but the share of private sector in electricity supply market is not comparable with the government sector's ones. In addition, the electricity selling tariffs were lower than the total cost of electricity generation. In other words, government sector have paid an enormous amount of subsides for electricity. Due to the reasons, the regional electricity companies are not profitable and thoroughly depend on the government budget. Moreover, the government- oriented electricity generation in Iran causes a lower energy and capital productivity in comparison with the world average [13]. From another point of view, Gas and water have the main contribution in the energy portfolio of electricity generation. Although, there are remarkable deposits of coal in Iran, the coal-fired power plants have not any share in electricity generation. Moreover, in spite of a great potential in electricity generation with renewable energies such as solar, wind and geothermal, there is a little effort in this area [13]. Yazd which is located in central Iran is among the driest cities in Iran, with an average annual rainfall of only 60 mm, with summer temperatures very frequently above 40℃ in blazing sunshine with no humidity. Although, Yazd has the greatest deposits of coal and numerous numbers of sunny days, Gas which is prepared from the southwest regions of Iran (Khozestan) is the only consumed energy in the energy generation. In addition to Gas, the coal and solar energies are the more applicable energies in electricity generation [13].

3. The Proposed SD Model

The proposed SD model is consisted of 10 main subsystems. Fig.1 illustrates the macro-structure of the proposed model with the subsystems and three main exogenous variables. The main exogenous variables in this model are GDP (Gross Domestic Production), inflation rate and technology change which makes a remarkable effect on the behavior of the electricity supply system. As it is shown in Fig.1, the considered subsystems and their main variables have many interactive relations. The subsystems are described as follows:

1. Electricity Demand Subsystem:

- GDP: GDP is an index that shows the amounts of production in different economies. As it is obvious, the amount of energy consumption (especially electricity) has a straight relation with GDP. Due to this relation, in this paper, GDP has been considered as an important input variable to analyze the future demand of electricity.
- Electricity Demand Intensity: Demand intensity which is the other main variable in this subsystem shows the amount of electricity that is consumed to obtain one unit of GDP. It is obvious that the lower amount of Demand intensity indicates the higher degree of electricity energy efficiency. In this research, the amounts of demand intensity in different sectors included domestic, industrial, service and agricultural sectors are considered to predict the electricity demand in different sectors and the total electricity demand.

In addition to the above variables, three significant variables, the effect of technology development (TD), the effect of demand side management (DSM) and the effect of tariff adjustment rate (considered Marginal benefit) in different sectors are the other main variables in this subsystem. These variables also have a significant effect on the amount of electricity peak demand which is the other main variable in this subsystem.

2. Electricity Generation Subsystem:

- The power provision methods considered in this work are Concentrated Generation (CG), Distributed Generators (DG), Demand Side Management (DSM) and energy importing (EI). One of the main objectives of this study is to determine the shares of different methods of power provision. In other words, defining the portfolio of power provisions are one of the main desired outputs.

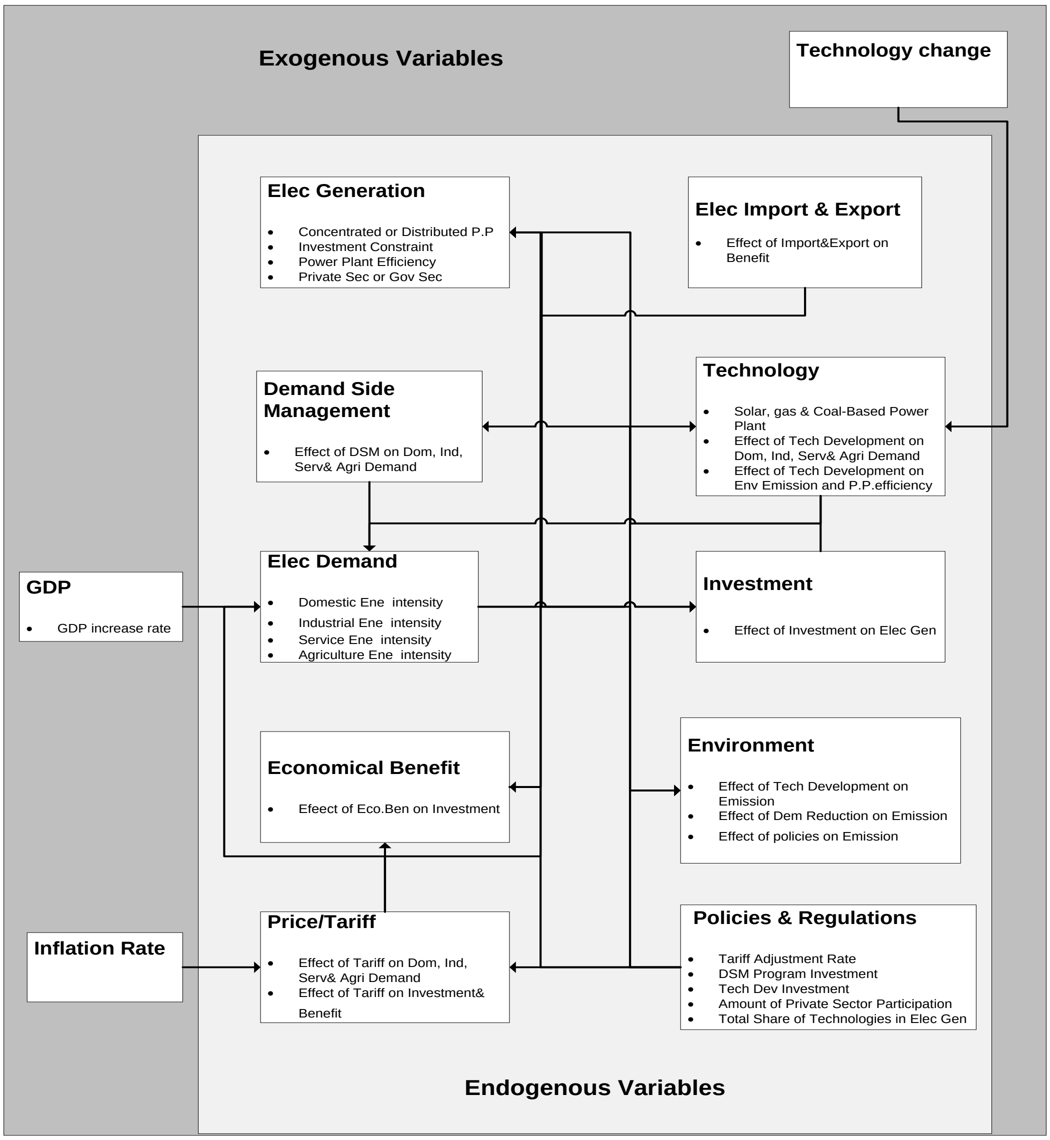

Figure 1: Macro-Structure of the Proposed Model

- Capital Constraint: The capital constraint is one of the main variables in the electricity generation subsystem. The fact that some of the required electricity generation capacities are not fully available due to the capital constraint, decrease the reliability of power generation.

- Power Plants Efficiency: Higher degrees of power plant efficiency cause lower amounts of new electricity generation capacities.
- Depreciation: Depreciation shows that what share of current electricity generation capacities are depreciated every year.
- Private Sector share in Power Generation: due to the limitation of government for investment in new power generation capacities and the low level of productivity in governmental power plants, the contribution of private sector is an incredible part of power generation subsystem. So far, the participation of Iranian private sector in power generation is not significant, but in coming years, the increasing trend of power demand and the lack of governmental financial resources will enforce the government sector to give more roles to the private sector.
- Technology Subsystem: defining the weights of different technologies in the portfolio of power generation technologies is one of the main variables in this subsystem. In this paper, the gas, coal and solar based power plants are considered as the most appropriate options in Yazd. Moreover, the variables of amount of investment in different technology development programs such as demand reduction, pollution reduction and increasing power plants efficiencies are the other important variables in this subsystem.

3. Environment subsystem: the effect of technology development programs on the pollution reduction, the share of different technologies in power generation programs and the effect of different policies on the demand reduction are the most important variables in this subsystem.
4. Price/Tariff Subsystem: The tariff adjustment rate, the unit price of power considering generated and imported power and the inflation rate, as an exogenous variable, are the main variables in this subsystem. On the other hand, the unit tariff of power has a straight effect on the amounts of demand, benefit and investment.
5. Policies and Regulation: In this subsystem, the endogenous variables that have regulatory aspect are considered. The tariff adjustment rate, the amount of investment on demand side management and technology development, the degree of privatization (amount of private sector participation) and the shares of different technologies in power generation are the main regulatory variables.
6. Economical Benefit: In this subsystem, the status of incomes, costs and total capital is considered. Variables such as tariff, electricity demand, amounts of exported electricity and the effect of economical benefit on investment are the main variables in this subsystem.
7. Export and Import Subsystem: the maximum proportion of imported power is one of the main variables in this subsystem. This variable shows that what share of electricity demand can be provided through importing. On the contrary, the maximum proportion of exported power, which shows the share of out of work power plant capacities that can be exported, is the other main variable in this subsystem. Moreover, the effects of power import and export on the economical benefit are the other main variables.
8. Investment Subsystem: the amount of private sector participation, degree of private sector interest in investment, the amount of investment in DSM and TD programs are the most important variables in this subsystem.
9. Demand Side Management Subsystem: Analysis of the effect of investment in DSM programs on the electricity demand of domestic, industrial, service and agricultural sectors is the main objective of this subsystem.

The VENSIM Software is applied for designing the casual loops and stock flow diagrams of the above subsystems. It should be noted that in designing process, there are no clear and distinct boundaries between the above mentioned subsystems. The existence of different interactions between the subsystems makes the overall system to be complex and unpredictable.

4. Validation of the Model

In this section, the validity of the proposed model is evaluated based on the historical data from 2000-2008. For this purpose, the year 2001 is considered as the base year and the simulation results of the model for period 2001 to 2008 are compared with the real data. For the sake of simplicity, only the real amounts of electricity demand are compared with the results of the model. As the electricity demand is the main variable which affect all parts of the model, an appropriate results for electricity demand gives some confidence on the results of the other parts of the model. Table.1 shows the results of proposed model compared with the real data in period 2001-2008.

Table 1: The real demands compared with simulated demands

	2002	2003	2004	2005	2006	2007	2008
Real Domestic demand (GWh)	492	547	601	664	720	784	843
Simulated Domestic Demand (GWh)	527	624	692	728	741	748	801
Real Industrial Demand (GWh)	1250	1500	1460	1050	1190	1360	1470
Simulated Industrial Demand (GWh)	1350	1580	1650	1530	1300	1250	1370
Real Service Demand (GWh)	334	344	369	406	445	482	460
Simulated service Demand (GWh)	337	394	438	460	470	456	494
Real Agriculture Demand (GWh)	381	424	486	525	537	544	578
Simulated Agriculture Demand (GWh)	385	439	486	526	562	600	647
Real Total Demand (GWh)	2160	2460	2810	2920	2650	2890	3170
Simulated Total Demand (GWh)	2160	2600	3040	3270	3250	3070	3050

As it is shown in table.1, the simulated results of the model have not a significant difference with the real amounts of demand; however in some cases, the model has had a lag in following the trends, but it could comprehend the trends effectively. Fig.2 which compared the real total demand with the simulated total demand shows the power of the proposed SD model in comprehension of the behaviors of the system.

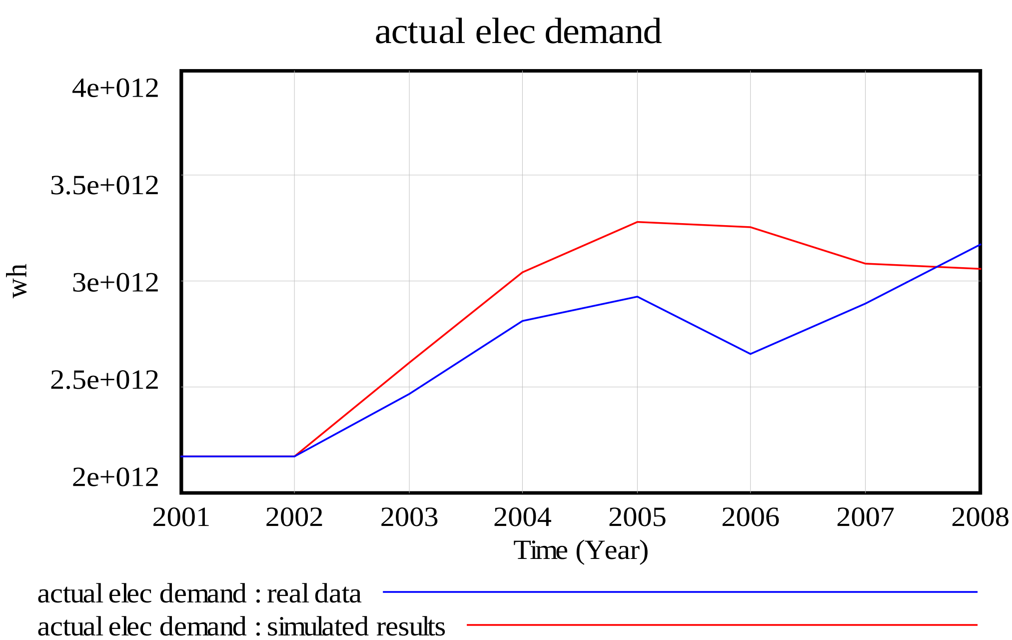

Figure 2: Real total demand- Simulated total demand

5. Analysis of the Proposed Model

In this section, the results of applying different scenarios and policies on the electricity supply system are analyzed. The scenarios are made with different amounts of exogenous variables that have significant effects on the outputs of the system. As it is shown in Fig.1, the inflation rate and the GDP growth rate are two important exogenous. In this study, 5 different scenarios are created based on different amounts of the variables. The policies, on the other hand, are based on different amounts of endogenous variables. In this study, 5 different policies are selected with different amounts of Tariff adjustment rate, share of government sector in power generation, the amount of investment in DSM and TD and the share of different technologies in power generation. The combination of the scenarios and policies make an appropriate way to understand the behaviors of the electricity supply system.

5-1- The scenarios and policies

Tables 2 and 3 show the considered scenarios and policies to analyze the electricity supply system in Yazd province.

Table 2: proposed scenarios

Scenarios	characteristics
Scenario A (Case Base Scenario): assume that the As Is conditions are preserved in the future.	Inflation rate= 10%, Total GDP growth rate =0.263, Industrial GDP GR= 0.302, Service GDP GR= 0.257, Agricultural GDP GR=0.198 [14].
Scenario B	This scenario assumes that the inflation rate is increased to 20%. The other variables are preserved.
Scenario C	This scenario assumes that the inflation rate is decreased to 5%. The other variables are preserved.
Scenario D	This scenario assumes 50% increasing in the GDP growth rate for different sectors. The other variables are preserved.
Scenario E	This scenario assumes 50% decreasing in the GDP growth rate for different sectors. The other variables are preserved.

Table.3: Proposed policies

Policies	characteristics
Policy 1 (Case base Policy): assumes that the As Is conditions are preserved.	Tariff Adjustment Rate: 43%; Share of Government investment= 100%; Share of DSM and TD Investment= 1% of budget; Share of Gas Power Plants= 100%
Policy 2 (Government-Oriented Policy): Assumes that government tries to preserve its dominance in power generation, But the electricity selling tariffs are adjusted in favor of government.	Tariff Adjustment Rate: 120%; Share of Government investment= 100%; Share of DSM and TD Investment= 1% of budget; Share of Gas Power Plants= 50%; Share of Coal-Fired Power Plants= 50%
Policy 3 (Private Sector-Oriented Policy): Assumes that government tries to decrease its dominance in power generation and improve its regulatory and controlling roles.	Tariff Adjustment Rate: 120%; Share of Government investment= 25%; Share of DSM and TD Investment= 1% of budget; Share of Gas Power Plants= 70%; Share of Coal-Fired Power Plants= 25%; Share of solar Power Plants= 5%
Policy 4 (Environment-Oriented Policy): environment conservation and decreasing power generation pollution are the main objectives of this policy.	Tariff Adjustment Rate: 140%; Share of Government investment= 25%; Share of DSM and TD Investment= 10% of budget; Share of Gas Power Plants= 80%; Share of Coal-Fired Power Plants= 0%; Share of solar Power Plants= 20%
Policy 5 (Balanced Growth Policy): Assumed balanced amounts for different variables to obtain balanced results in different aspects.	Tariff Adjustment Rate: 100%; Share of Government investment= 50%; Share of DSM and TD Investment= 5% of budget; Share of Gas Power Plants= 75%; Share of Coal-Fired Power Plants= 25%; Share of solar Power Plants= 0%

In order to analyze the performance of different scenarios and policies, the amounts of pollution and the unit cost of electricity are considered as environmental and economical performance indices. In addition to these indices, the electricity demand is the other variable that has been considered to analyze the results.

5-2- Scenarios and Policies Analysis

Considering 5 different scenarios and policies, there is 25 different instances in the analysis of the SD model. In this section, the results of 3 performance indices for different 25 instances in period 2009-2020 are studied.

5-2-1- Electricity Demand

Table.4 shows the maximum and minimum amounts of electricity demand in 2020 for different scenarios. As it is shown, the maximum amount of electricity demand in all scenarios is happened in policy A (Case base policy). On the contrary, the environment-oriented Policy (policy D) which has had maximum share of DSM and TD investment and maximum amount of tariff adjustment rate has minimum amounts of electricity demand in all scenarios. For instance, in the case base scenario, the amount of electricity demand for policy 4 is 40% lower than case base policy.

Table 4: The Results of Electricity Demand in Different Scenarios

Scenario	**Max expected Demand (GWh)**	**Max Related Policy**	**Change (%)**	**Min expected Demand (Gwh)**	**Min Related Policy**	**Change (%)**
Scenario A	8700	case base Policy	0%	5220	Policy 4	- 40%
Scenario B	8230	case base Policy	-5%	5220	Policy 3,4	- 40%
Scenario C	10100	case base Policy	16%	5270	Policy 4	- 39%
Scenario D	28700	case base Policy	>200%	17200	Policy 4	98%
Scenario E	3720	case base Policy	-57%	2280	Policy 4	-74%

On the other side, scenarios D and E, which have had the maximum and minimum GDP growth rate, have maximum and minimum amounts of electricity demand, respectively. The minimum expected demand of these scenarios show 98% and -74% change compared with the case base scenarios. Moreover, scenario C which has had minimum inflation rate, have a high amount of electricity demand.

5-2-2- Unit Price of Electricity

Based on the results of case base scenario, the Maximum and minimum unit price of electricity in 2020 will be 2490 (R/KWh) and 2020 (R/KWh), respectively. Table.5 shows the amounts of unit price of electricity for different scenarios and policies. As it is obvious in table.5, the minimum and maximum unit price of electricity will occur in balanced growth policy and case base policy, respectively.

Table 5: Unit price of electricity in different scenarios

Scenario	Max Price (Rial/kWh)	Max Related Policy	Change (%)	Min Price (Rial/kWh)	Min Related Policy	Change (%)
Scenario A	2490	Case base Policy	0%	2020	Policies 5	-19%
Scenario B	6840	Case base Policy	175%	6280	Policies 5	150%
Scenario C	1480	Case base Policy	-41%	1100	Policies 5	-56%
Scenario D	2790	Case base Policy	12%	2020	Policies 5	-19%
Scenario E	2490	Case base Policy	0%	2020	Policies 5	-19%

In another view, the minimum unit price of electricity will be in scenario C with 5% inflation rate and the maximum unit price of electricity will be in scenario B with 20% inflation rate. Based on the results, the minimum unit price of electricity in 2020 will be 1100(R/KWh) in scenario C and the maximum ones will be 6840 (R/KWh) in scenario B.

5-2-3- Amounts of pollution

As it is shown in Table.6, according to the prediction, the environment-oriented policy will have the minimum and the balanced growth policy the maximum amounts of pollution. Based on the results, a 30% reduction in the amount of pollutants will be occurred with the application of environment-oriented policy. Considering the scenarios, scenarios B and D have maximum amount of demand and consequently maximum amounts of pollution.

Table 6: Amounts of Pollution in Different Scenarios

Scenario	Max pollution (gr)	Max Related Policy	Change (%)	Min pollution (gr)	Min Related Policy	Change (%)
Scenario A	8.33 E12	Policy 5	0%	5.8E 12	Policy 4	-30%
Scenario B	8.16E 12	Policy 5	-2%	5.63E 12	Policy 4	-32%
Scenario C	8.54E 12	Policy 5	3%	5.95E 12	Policy 4	-29%
Scenario D	1.43E 13	Policy 5	72%	9.2E 12	Policy 4	10%
Scenario E	6.2E 12	Policy 5	-26%	4.4E 12	Policy 4	-47%

As it is shown in Tables 4-6, two policies 4 and 5 (environment-oriented and balanced growth policies) represent the best results among different policies. As it is obvious, environment-oriented policy has minimum amounts of pollution as well as minimum amount of electricity demand. In other words, the minimum amounts of pollution in environment-oriented policy is not only because of application of solar power plants and omission of coal-fired power plants, but also because of demand reduction resulting from maximum amount of investment in DSM and TD and maximum amount of tariff adjustment rate.
On the other hand, as the balanced growth policy has not huge amounts of electricity demand and pollution, it has minimum unit price of electricity among policies. Considering case base scenario as the more likely scenario, Fig.3 compares the environment-oriented and balanced growth policies for different performance indices.

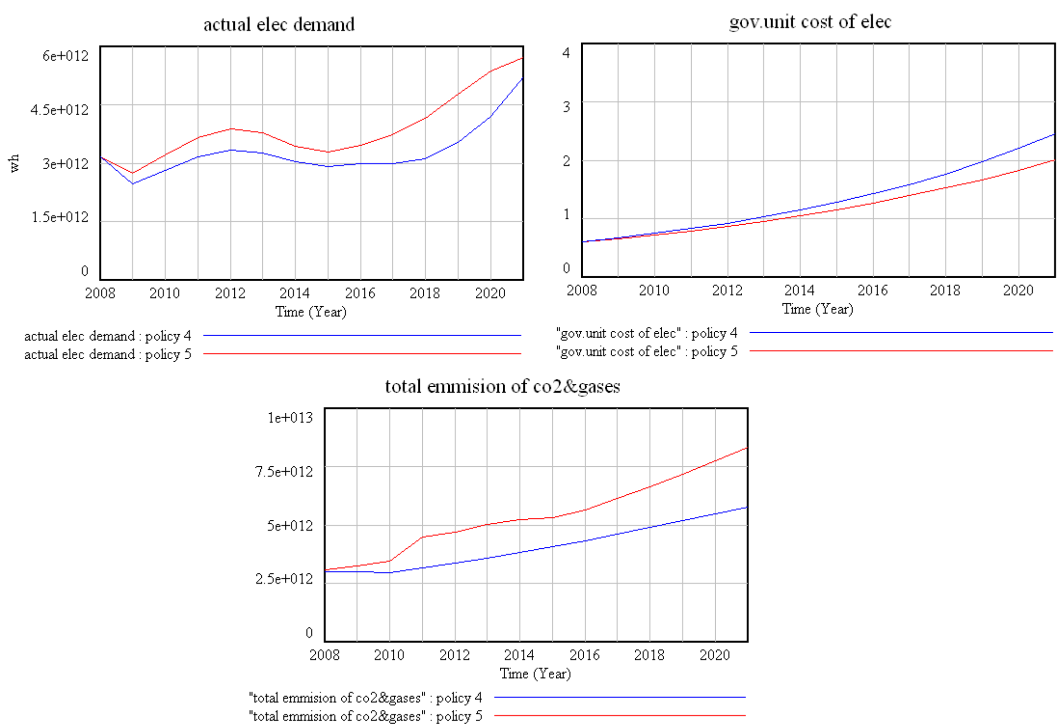

Figure 3: Environment-Oriented V.S Balanced Growth Policy

6. Conclusion

In this paper, a comprehensive system dynamic model comprising all different subsystems of electricity supply system is introduced. The capability of system dynamics in dealing with the dynamism of different complex systems in addition to the high level of flexibility and accuracy in system analysis make it as one of the most favourable techniques in handling complex systems. The effectiveness of the model in handling the dynamism of system and analyzing policies is validated with a real case in province of Yazd in Iran for period 2009-2020. For this purpose, 5 different scenarios and policies are considered to analyze the electricity supply system. The result of the model is evaluated based on different environmental and also economical criterion. Based on the results, the environment-oriented and balanced growth policies show the best results. In addition to the obtained results, it is possible to apply other scenarios and policies on the proposed model and analyze the behavior of electricity supply system. In other words, the proposed model is a flexible model to analyze a wide variety of problems in the domain of electricity supply system.

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