The Effects of Energy Consumption on Environmental pollutants and Social Costs in Iran Using System Dynamics Approach

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Abstract

Energy consumption has constantly been increasing during these years. Excessive energy consumption causes reduction in energy sources as well as making environmental pollutants which demands high social costs in the society. Due to the inappropriate methods employed in most studies on energy consumption, all-inclusive effects of excessive energy consumption has not been dealt with. System Dynamics, on account of its comprehensibility, can be an effective method to detect and investigate energy consumption effects. So, in this study, System Dynamics approach was used to analyze effects of energy consumption on the environmental pollutants and social costs in the planning horizon of 2024 in Iran. Simulation results indicated that energy consumption in 2024 would reach to 2150 million barrels of oil. On this basis, environmental pollutants would reach from 283 million tons in 1999 to 1185 million tons in 2024 horizon. The rate of social costs would be equal to 28875 million dollars. This cost is equal to 27% of GDP. The findings suggest that energy consumption in the future creates several problems in providing energy sources as well as social costing and health. A lot of problems would be created in the environment and healthcare of the society in case of not planning for the excessive energy consumption.

Key Words*: Energy Consumption, System Dynamics, Environmental Pollutants, Social Costs, Energy intensive.*

JEL Classification*: C32, C53, C61, Q48, Q53, Q52*

1. Introduction

The intensity index, that in a way calculates the amount of energy consumption per added value, is in a very undesirable condition in Iran, compared to developed countries. This places Iran behind Russia with the second position worldwide.

Moreover, the intensity of energy in Iran is 14 times higher than that of Japan, 8 times higher than that of developed countries and 2.5 times higher than that of other countries of the Middle East region. The process of variation in the index demonstrates its developing condition within recent years so that the average energy intensity index of the country has increased from 1.59 in 1999 to 1.78 in 2008. (Energy Balance Sheet, 2008). The high energy intensity not only creates numerous environmental pollutants, but also makes up social costs and damages on the public health.

Marginal costs caused by energy consumption usually are not considered during decision making processes. Instead, efficiency of energy consumption based on value added as compared to the consumed energy is calculated. It must be noted; however, that the effects of energy consumption are not solely restricted to the value added index and the cost of the consumed energy.

As a matter of fact, marginal effects, that gradually influence the environment and public costs, are far more significant than the rest of the elements and unfortunately have not yet attracted attention, due to non-transparent consequences and prolonged obtained results. Therefore, to gain a true and logical understanding of the effects of energy consumption on social costs, an all-inclusive study of the aspects of the subject should be conducted using a proper method. Because of its comprehensiveness and desirable capabilities, systemic approach can be useful to achieve that goal. To this aim, the level of environmental contaminants and social costs (i.e. environmental and health costs) of energy consumption of Iran in 2024 horizon was simulated in the present article with regard to the actual information of the applied variable from 1999 to 2008 using system dynamics method. In addition, policies required to improve the condition are presented accordingly.

For this purpose, in this research, after reviewing the related literature, the effects of energy intensity on Environmental pollutants and social costs will be modeled by using of System Dynamics approach. Then, this model is simulated in 2024 horizon. In the final stage, several scenarios for policy making will be appraised and recommendation will be proposed for better condition.

2. Background

The subject of environmental economy and social costs have come in to consideration of specialists mainly from the late 1950s onwards due to an increase in irregular energy consumption, environmental costs and social health. Meanwhile, the Environment Kuznets Curve (1995) describing the relationship between the economic growth and environmental destruction in the form of an upside-down U was more noteworthy than the rest of theories. Kuznets believed that environmental costs in developing countries would initially increase with an ascending slope. But, when these developing countries reach a desirable level of economic growth and development, energy consumption and its related costs will decrease significantly in a descending slope due to the generation of environmental pollutants and the government sensitivity in public health. Later on, the theory was approved in many countries. Beckerman (1992), among others, proved the relationship between economic growth and the costs of environmental destruction in

Germany by providing experimental evidence using Kuznets Curve. Elsewhere, Carlos (2007), Roca and others (2001) established the authenticity of this hypothesis in Spain. The results of their study indicated that social costs due to energy consumption in this country had been equal to 15 percent of the level of gross domestic product in 2007.

Mayer and Kent (2000) believe that energy consumption and environmental pollutants are closely related and that the energy sector exhibits the highest effect on creation of social costs due to environmental pollutants (Shim ,2006).

Ang (1994) in his study evaluated the relationship between energy consumption and environmental costs in Taiwan and Singapore between 1971 and 1990 by means of Divisia Index. The findings specified that with respect to the improvement of energy consumption index, social and environmental costs decrease as well. He also analyzed the relationship between the economic growth in France and the level of environmental pollutants in 2007. His findings indicated that economic growth was the main cause of energy consumption and formation of pollutants in this country.

Alam, Fatima and Butt (2007) have analyzed the elements affecting Pakistan's pollutants between 1971 and 2005 and came to the conclusion that the high intensity of energy in this country constitutes the main cause of formation of pollutants and environmental costs.

Halicioglu (2009) attempted to empirically examine the dynamic causal relationships between carbon emissions, energy consumption, income, and foreign trade in the case of Turkey using the time-series data for the period 1960-2005. The empirical results suggested that income was the most significant variable in explaining the carbon emissions in Turkey which was followed by energy consumption and foreign trade. Moreover, there existed a stable carbon emissions function.

Mutafoglu (2012) investigated the relationships among Foreign Direct Investment (FDI) inflows, Carbon Dioxide (CO_2) emissions, and economic growth in terms of Gross Domestic Product (GDP) for Turkey over the period of 1987–2009. The results suggested that there was a stable long-run equilibrium relationship among the variables under consideration. The results of the Granger causality test showed that there was a causal relationship between the variables and lend support to the pollutants-haven hypothesis. However, there appeared to be no evidence of FDI-led growth in the data.

In Iran, likewise, there have been a number of studies conducted on energy consumption and its environmental effects. The results of this studies showed a positive relationship between energy consumption, economic growth and carbon emission. Moreover, Behboodi, Fallahi and Golazany (2009) investigated the relation between CO2 emission and environmental costs with Granger Causality Method. The results showed that energy consumption, CO2 emission and value added are related. Behboodi, Kiani and Ebrahimi (2011) investigated the relationship between CO2 emission and costs of energy using. The results showed that energy consumption is related to CO2 emission and value added.

A review of the earlier studies demonstrates that the majority of the conducted researches in the field of energy consumption and environmental costs, particularly in Iran, have been based on Econometrics Methods. Considering the widespread consequences of energy consumption, these methods failed to assess and calculate these outcomes because of their non-inclusive approach. However, the system dynamics method is comprehensive and can be helpful in this matter.

System dynamics first proposed by Forrester (1946) to identify and explain the behavior of complex systems and the way they interact. He assumed that system dynamics, through focusing on feedback and causal relationship, is able to identify and explain the relationship among various systems. Regarding the potentials of the method, in recent decades, it has had many applications in the fields of environment and energy. In addition, various models have been designed and applied accordingly.

The first application of system dynamics method was carried out in early 70s in MIT by Forrester (1978) to investigate the energy condition in the world and the challenges ahead particularly in the field of environment. Moreover, Backus (1996), Bunn, Larsen and Fidman (1997), Ford (1990) and Naill (1977) used system dynamics model to study energy consumption and environmental effects.

Longbin (2007), using system dynamics model, simulated the condition of energy consumption and creation of environmental pollutants in China steel industry from 2007 to 2100. The findings illustrates that the highest level of energy consumption in this industry will be in 2025. For this level of energy consumption, the amount of pollutant gases in the same year will hit 1 billion tons, imposing high costs equal to 255 billion dollars on the society.

System dynamics model was also used by Li and Dong (2012) in Gansu province, China to evaluate the effects of energy consumption pollutants on the environment. The simulated horizon designated for the study was from 2009 to 2050. The model results exhibited that the maximum effective time of energy consumption on the environment would be in 2027. So that, the measure of pollutant gases, particularly CO_2, will reach 325000 tons in the same year and in consequence, cost 250 million dollars of social expenses for the government and society.

Despite of the capability of system dynamics model, it has not yet been utilized in Iran to analyze aspects of energy consumption and environmental effects. For this purpose, the method will be used in the present study to assess the effects of energy consumption on environmental indicators and social expenses incurred by pollutants' production.

3. Research Method

Complex behaviors of economic and social systems affect each other increasingly and the final behavior of the system is specified through this effect and feedback process. With regards to system dynamics method in analyzing various issues and effective variables in energy consumption, this study explores the effects of energy consumption on environmental indicators and social expenses of social costs based on seven-stage model of Sterman (2000:86). Following stages are described as follows:

3.1 The statement of the problem and dynamic subject

At this stage, the purpose of the model, key variables and temporal horizon is specified. With regard to the subject of the study, the purpose of the model is to "assess the effects of energy consumption on the environment and public social costs". Key variables are energy consumption, social costs, environmental pollutants, and so on. Temporal horizon chosen for simulation is a 25 year period from 1999 to 2024 (planning horizon of the country). For this purpose, initially through the use of actual information between 1999 and 2008, the behavior of the investigated variables is simulated and after ensuring the accuracy of behaviors, their variation process is simulated and assessed until the expected horizon. Considering the subject of the study, it encompasses energy consumption (fossil fuels, electricity, gas and crude oil products) per "barrel of crude oil". That is to say, the main focus is on evaluating the effects and outcomes of energy consumption on the environment and public social costs.

3.2 Definition of key variables and creating dynamic relationships

According to the subject of the research and system dynamics model, numerous variables have an effect on the process of energy consumption and environmental costs. At this stage, only main influential variables, based on which policies are made, are introduced.

3.2.1 Total energy consumption

Considering the process of energy consumption, in this model energy consumption is considered to be dependent on the consumption rate of the previous periods and the coefficient of consumption improvement. According to available statistics, the amount of energy consumption in Iran was equal to 623 million barrels of crude oil in 1999 that reached a high of 1166 million barrels in 2008 with the average annual growth of 6.5 percent (energy balance sheet, 2008: 39-43).

3.2.2 Energy Intensive

It shows how much energy is consumed to create one unit of added value. Based on system dynamics model, energy intensive improves energy consumption and added value and affects future energy use.

3.2.3 Environment and social costs

Current process of energy use has confronted the country with two major crises: environmental pollutants and acceleration in the reduction of energy sources. In addition, the phenomenon of climate change and non-renewable energy sources are the main challenges of energy consumption. Moreover, crises mentioned above, have continued more severely in recent years due to incorrect consumption pattern and unstable development. Hence, appropriate use of energy has a key role to improve environmental conditions and decrease marginal costs of energy consumption considered as social costs. Social cost is one that is created as a result of damaging effects of environmental pollutants on ecosystem and public costs. In other words, total cost to compensate for damages done by the release of pollutants are called social costs (energy balance sheet, 2008: 272).

Taking into account the amount of energy consumption in Iran, the rate of pollutants caused by that was equal to 283 million tons in 1999 that reached a high of 560 million tons in 2008. Social costs (environment and health) of the creation of these pollutants were equal to 3915 million dollars in 1999 and boosted to 7022 million dollars in 2008(energy balance sheet, 2008:273).

3.3 Designing system dynamics diagrams and determination of variables

At this stage, considering the relationships among variables, the systemic relationship of defined variables and how they impact each other are determined in the form of cause and effect relationships (figure 1). Used variables are divided in to three groups:

State variables

They show accumulation over a period of time and rise or fall during the time on the basis of rate variables. The most important state variables defined in this model are energy consumption level, environmental pollutants, social costs, and so on.

Rate variables

They determine State variables in the system, like energy consumption rate, environmental pollutant emission rate, and so on.

Auxiliary variables

They consist of other variables and their quantity is not dependent on the previous term values, such as standard of environmental costs, population, etc.

Regarding system dynamics diagram (figure 1) and B1 loop, energy consumption per barrel of crude oil based on pollutant emission rate creates pollutants levels. Pollutants level also has an effect on social and environmental costs taking pollutants cost index into account. Finally, whereas the polarity of the loop is a balanced one, with an increase in pollutants cost the society has to consume energy less so as to maintain this equilibrium. It is obvious that reduction of energy consumption diminish pollutants and helps public and environmental health. Considering the effect of energy consumption on environmental conditions, social costs following that also has a main influence on society costs and gross domestic product (GDP). Moreover, based on the balanced loop, per capita environmental pollutants are calculated according to pollutants level and population. Since a rise in pollutants has disastrous consequences for the society, there are balanced changes in the loop that control pollutants levels.

Based on B3 loop, energy consumption influences energy demand and determines energy cost, and at the end, energy cost also affects energy consumption. In addition, based on R1 loop, a rise in energy consumption leads to an increase in Energy Intensive. A rise in Energy Intensive causes a decrease in added value and at last, a decrease in added value brings about less energy consumption. Therefore, in this loop also added value controls the consumption[1].

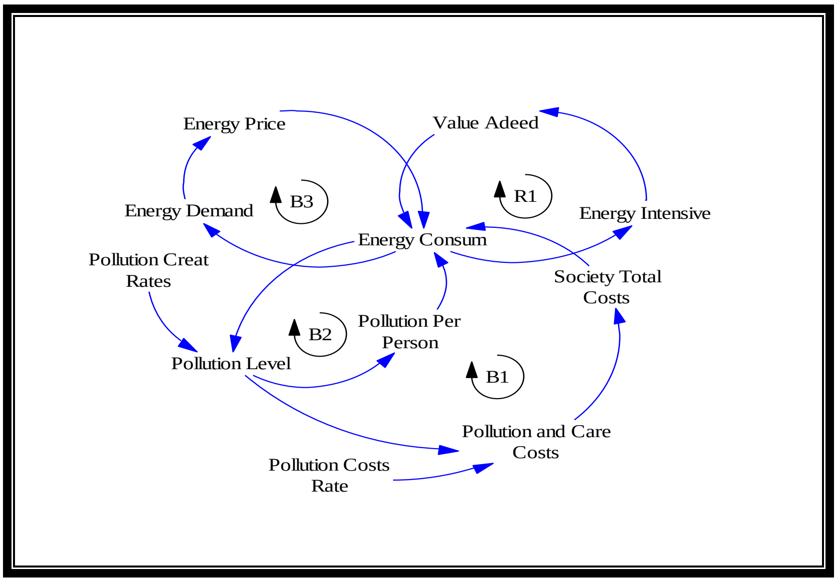

Figure 1: Cause and effect relation between energy consumption and environmental pollutants

[1] - In the appendix 1, the relations among variables have been are shown.

3.4 Formulation and definition of the relationships among variables based on mathematical relations

At this stage, the quality of behavior and effects of variables on each other is defined in the form of mathematical functions and relations.

3.5 Model Validation

After relationships among variables are defined, the credibility of designed model was evaluated in order to make sure of its appropriate function. In order to make certain about the validity of the model function and defined relationships, several tests were performed using Vensim DSS software. What follows shows the results:

3.5.1 Behavior reproduction tests

The aim of the test is to compare simulated results with real ones so as to be confident about the accuracy of model behavior function. Figures 2 and 3 demonstrate actual data and simulated results of energy consumption variable, the amount of environmental pollutants and social costs between 1999 and 2008. As it shows, the behavior of examined variables is simulated very well.

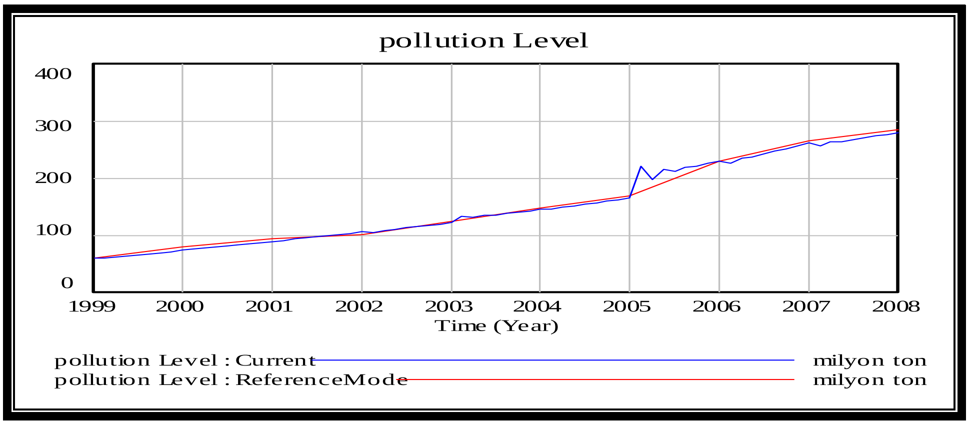

Figure 2: Reproduction behavioral test for pollutants production[2]

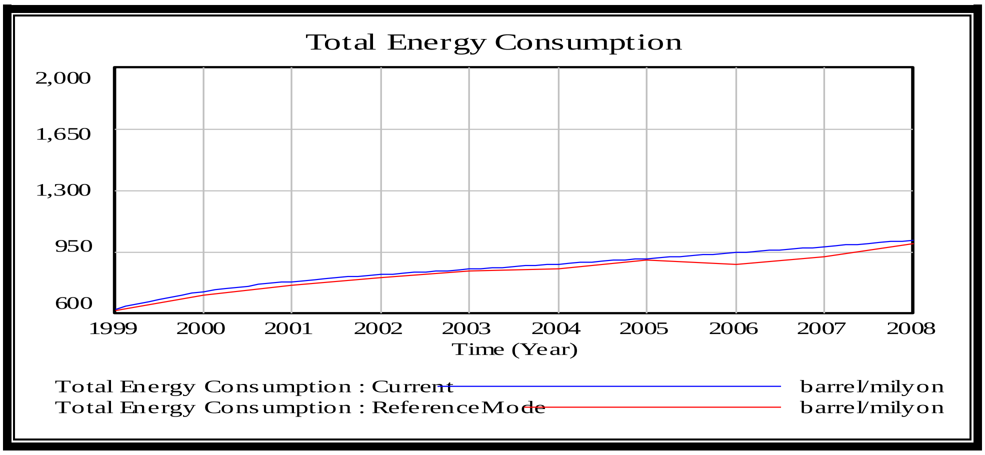

Figure 3: Reproduction behavioral test for energy consumtion

[2] - The deviation of pollutants level is related to computatational errores of the model in 2005.

3.5.2 Measurement error test

Besides the reproduction of model behavior, error rate of key variables were also measured by horizon 2024 with the following methods in order to be assured about simulated results (Sterman, 2000: 874-877).

Root mean square percent error (RMSPE)

Based on this index, the fewer differences between real and simulated data, the more reliable simulated data will be. The error rate is estimated by:

$$\text{RMSPE} = \sqrt{\frac{1}{\theta}\sum_{i=1}^{\theta}\left(\frac{y_{T+i}^{s} - y_{T+i}^{a}}{y_{T+i}^{a}}\right)^{\wedge}2} \times 100$$

In this formula:

y_{T+i}^{s}= simulated results of model variable

y_{T+i}^{a}= real data

θ= the number of observations

On this basis, the closer RMSPE to zero the fewer the errors become. on the contrary, the closer RMSPE to 100 the more the errors become. The results obtained by error calculation tests are shown on the basis of key variables in table 1. As it shows the error rate in all examined variables is very low.

Error roots

Whereas errors have a key role to increase the accuracy of anticipated results, error roots are related to three factors:

1. Base error (U^m): It appears when model results are not compatible with the data.
2. Deviation error (U^s) : It comes out when variances of real data and simulated ones are very different.
3. Covariance inequality error (U^c): It emerges when there is no correlation between the model results and the data.

Table 1: Model Errors Test Results Based on Simulation Duration

Model key variables	The minimum amount of RMSPE (percent)	Calculation of error roots		
		U^m	U^s	U^c
Total energy consumption	15.4	0./012	0./016	0./97
Energy intensive	1.82	0./16	0./18	0./66
The production of pollutants	1/03	0./048	0./0136	0./94
Social costs of the pollutants	7.3	0./0044	0./2	0./796

3.5.3 Extreme condition test

The precision of simulation usually declines in longer periods of simulation. Therefore, the results of simulation may be affected by time scale. In order to be assured that model results are not influenced by time scale, timetable was taken in to account until 2034. Simulation results indicated the accuracy of model behavior in future years.

4. Results

Regarding the recognition of main variables and mutual relationships among them, this model was simulated for a 25-year period (from 1999 to 2024) by the use of Vensim DSS software. Key variables results were determined as follows**:**

4.1 Energy consumption

Simulation results in figure 4 indicate that total energy consumption in 1999 is equal to 620 million barrels and will reach a high of 2150 million barrels in 2024. The results show that energy consumption is rising all the time except in a short term period of energy subsidy reforms when it is falling. It is worth mentioning that coefficient of annual consumption improvement is also taken in to account in the simulation of energy consumption. Since the volume of energy consumption boosts in 1999, internal consumption accounts for 60 percent of energy production and will reach a high of 83 percent in 2024 horizon.

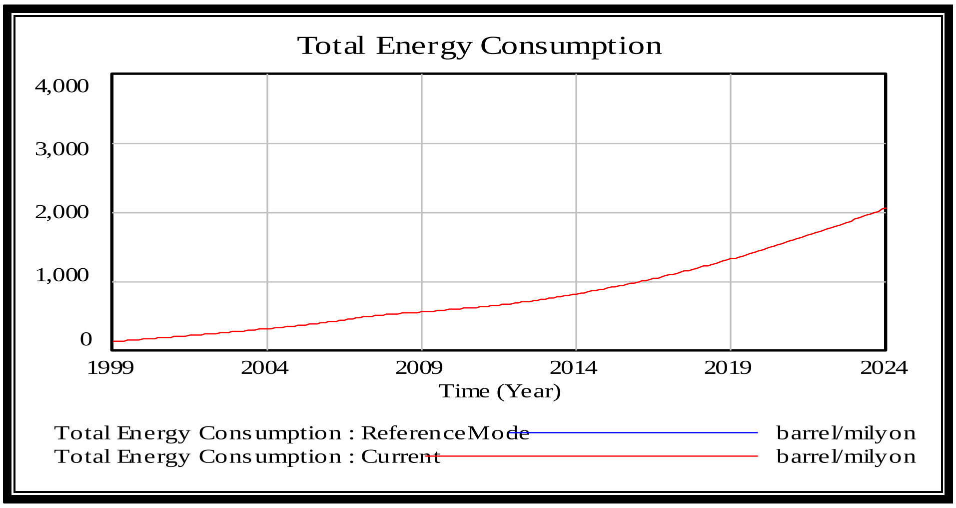

Figure 4: Simulation of energy consumption in all sectors

4.2 Environmental pollutants and social costs

As simulation results about environmental pollutants signifies, the amount of pollutant creation in 1999 is equal to 283 million tons that will reach a high of 560 and 1185 million tons in 2008 and 2024 respectively. On this basis, the amount of pollutant creation is approximately 4.5 times as high in 2024 as it was in 2008. As it shows (figure 5), the creation of environmental pollutants has a rising trend to the end of simulation period and it is proportionate to the increase in energy consumption. Moreover, Per capita pollutants index, showing the amount of created pollutants per person in the country, is also increasing constantly during the period. Considering the creation of environmental pollutants in 1999, per capita pollutants per person is about

875 kilograms. On this basis, regarding that the population reaches 88.19 million by 2024, per capita pollutants of consumed energy will be equal to 4190 kilograms. Simulation results for environmental costs of energy consumption in figure 6 indicates that ,taking the creation of environmental pollutants in to consideration and social costs of pollutants in 1999 are equal to 3915 million dollar that will reach a high of 28875 million dollar by 2024.

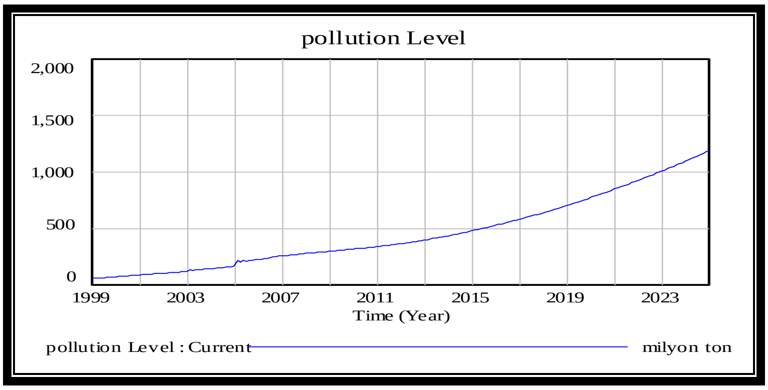

Figure 5: Results of environmental contaminants simulation

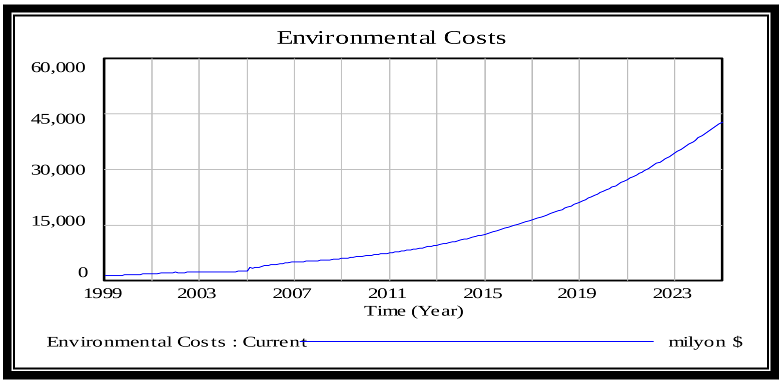

Figure 6: Results of production of costs of environmental contaminants simulation

4.3 Energy Intensive

Energy Intensive index shows the amount of energy consumption per added value. At the beginning of the examined period, 2.67 barrel of crude oil is used for the production of 66.67 dollar added value. It reaches to a high of 2.685 and 2.704 barrels in 2008 and 2024 respectively. The results show that not only energy intensive gets worse, but also increases. Since, the rise in energy Intensive index affects energy consumption, these mutual influences finally leads to more energy consumption in future periods.

4.4 Policy making for the optimization of key variables

The aim of this stage is to optimize key variables according to different policies. The model results are analyzed based on the policy of energy intensive reduction on key variables concerning effective variables and different scenarios.

4.2.1 The effect of energy intensive reduction policies on energy consumption

The amount of energy intensive in the present condition (2012) is equal to 2.69 barrels (figure 7). Based on this, as well as the continual of the present condition (green line), two policies are made:

1. 5 percent annual reduction of energy intensive (red line) and
2. 10 percent annual reduction of energy intensive (blue line)

The results of the implementation of these scenarios indicate that:

- If the present condition policy goes on, energy consumption rate in 2012 is equal to 1150 million barrels that will reach a high of 2150 million barrels in 2024 horizon.
- With a 5 percent annual decrease in energy intensive from 2012, energy consumption will reach a low of 1850 million barrels in 2024 horizon.
- With a 10 percent annual decrease in energy intensive from 2012, industry consumption will reach a low of 1600 million barrels in 2024 horizon.

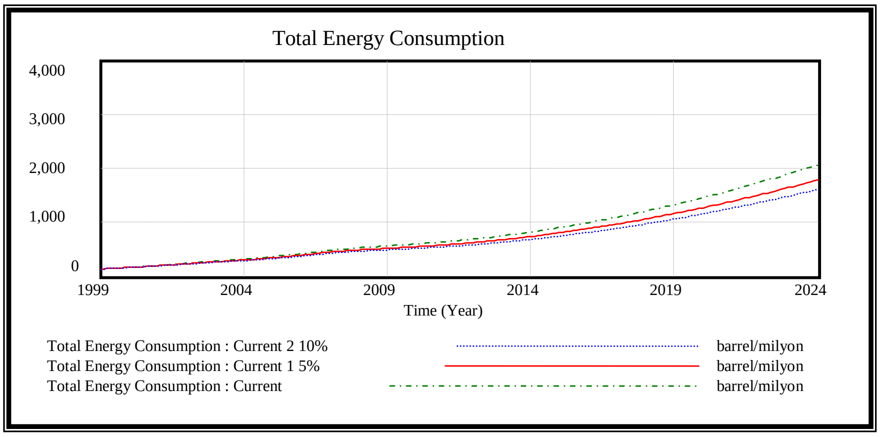

Fig 7: Energy consumption simulation

4.2.2 The effect of energy intensive reduction policies on environmental pollutants and social costs

Considered scenarios to analyze the effect of energy intensive reduction on environmental pollutants and social costs point out that:

- If the present policy goes on (figure 8), the amount of environmental pollutants in 2012 horizon is equal to 420 million tons that will reach a high of 1500 million tons. Moreover, social costs caused by these pollutants increases from 8.2 to 33.3 million dollar.
- with 5 percent annual reduction in energy intensive from 2012,the amount of produced pollutants in 2024 horizon reach a low of 1350 million tons and social costs of these pollutants will boost from 6.7 million dollar to 28.5 thousands of million dollar.
- With 10 percent annual decrease in energy intensive from 2012, the volume of environmental pollutants in 2024 horizon reach a low of 1100 million tons. environmental costs of this pollutants decrease from 39 thousands million dollar to 30 thousands of million dollars.

Figures 8 and 9 present the effects that variation process of energy intensive rate has an effect on the production of pollutants and social costs based on three suggested scenarios.

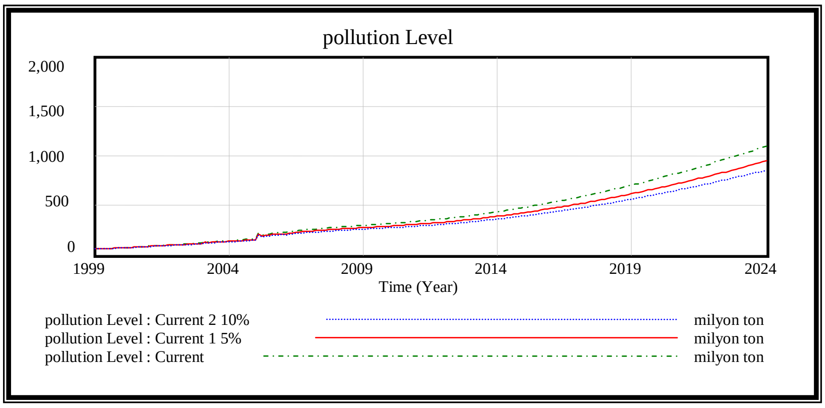

Fig 8: Results of energy intensive change on pollutants level

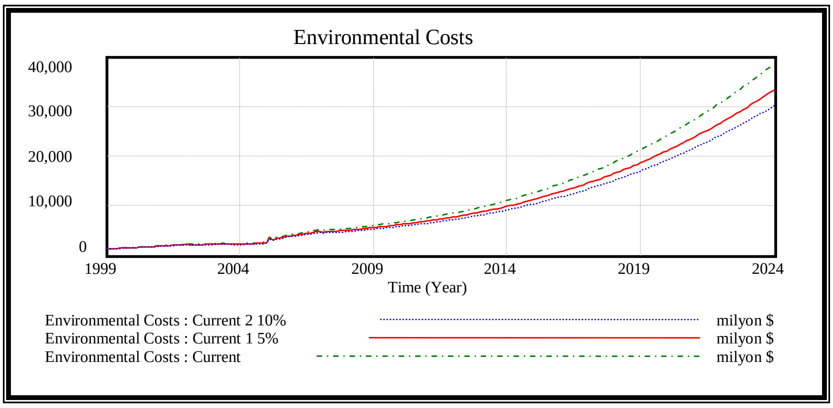

Fig 9: Results of energy intensive change on environmental and social costs

5. Discussion

One of the main objectives of current study is to examine the process of Iranian energy consumption in 2024 horizon and its influence on social costs. Because of irregular energy consumption, Iran encounters many problems to provide energy, and it charges the country a lot of social costs (health and environmental). As the results of the study show, environmental costs account for about 21.5 percent of GDP in 2008 that will reach a high of 27 percent in 2024 horizon. Whereas studies performed by Carlos (2007) in Spain showed that the environmental costs account for about 15 percent of the country's GDP. In this condition, it is a main concern to make appropriate policies in order to reduce energy consumption and environmental pollutants and in conclusion increase public health.

If the present amount of energy consumption continues, not only environmental pollutants and social costs will not fall in 2024 horizon, but also they will rise with an upward slope. In other words, increase in environmental pollutants and social costs caused by them are not main concerns because of Iran's transition to development. Therefore, to adapt the production of environmental pollutants in the country with Kuznets Curve (1955) indicates that production process of the pollutants and social costs of it do not follow this curve. However, this process is approximately in conformity with the curve for Pakistan until 2020 shown by a study done by Alam (2007).

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Appendix 1

Variable name and specification for system dynamics modeling

Variable Name	Unit	Variable Type	Formulation	Constant Quantity
Energy Demand	barrel	Auxiliary	Energy consumption in latest year * consumption increase rate per year	923 million in base year (1999)
Energy Consumption	barrel	Level	Energy consumption last year *(Energy Price*1/ $e^{-.256\ value\ adsed}$) –(1/ pollution per person)	623 million in base year (1999)
Energy Price	barrel	Auxiliary	-	91.5 $ per barrel
Pollution Level	barrel	Level	Energy consumption (barrel)*pollution rate produce for each barrel	-
Pollution and Care Costs	barrel	Auxiliary	pollution level(million ton) * pollution cost per ton	-
Pollution per Person	ton	Auxiliary	pollution level (with delay)/population	-
Pollution cost per barrel	dollar	Auxiliary	-	9.4 $ per ton
Energy intensity	Barrel per dollar	Level	Energy cost / value added	-
Energy cost	dollar	Auxiliary	energy price (per barrel)*energy consumption	91.5 $ per barrel
Pollution Cost rate	dollar	Rate	-	-
Pollution rate	ton	Rate	-	0.48 ton per barrel

Appendix 2

Energy production and consumption in the System Dynamics model