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The Effects of Domestic Energy Consumption on Urban Development Using System Dynamics

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Abstract. In developed countries, people have learned to follow efficient consumption patterns, while in developing countries, such as Iran, these patterns are not well executed. A large amount of energy is almost consumed in buildings and houses and though the consumption patterns varies in different societies, various energy policies are required to meet the consumption challenges. So far, several papers and more than ten case studies have worked on the relationship between domestic energy consumption and urban development, however these researches did not analyzed the impact of energy consumption on urban development. Therefore, this paper attempts to examine the interactions between the energy consumption and urban development by using system dynamics as the most widely used methods for complex problems. The proposed approach demonstrates the interactions using causal loop and flow diagrams and finally, suitable strategies will be proposed for urban development through simulations of different scenarios.

1. Introduction

Energy is one of the primary requirements for industrial and commercial goals of each country and has an important role in the country's rapid socio-economic growth and improvement of the quality of life [1], [2]. Also it is considered as a determining factor for employment, economic competitiveness and social welfare [3]. In 2007 energy consumption in the world was 495 quadrillion and it is predicted that it will reach 739 quadrillion by 2035. This represents 1.4 percent of annual growth for energy consumption in the world [4]. Undoubtedly, depending on the type of consumption pattern, level of development and economic growth, energy consumption is varied in different countries [5], [6].
In 2007 energy consumption in non-OECD countries first surpassed as much as 1.5 percent by OECD. It is expected that the difference in energy consumption between OECD and non-OCED will increase to 32% by 2035. Today, the rapid growth in demand and consequently the decline of non-renewable resources and increasing pollution, led to the environmental and energy crisis because, along with consumption, production and supply methods of energy are of effective factors in greenhouse gas emissions and environmental pollutants [7]-[9]. Researchers, managers and politicians are trying to provide appropriate programs to limit energy consumption. Today, two-third of total world energy consumption and CO_2 gases emissions is related to urbanization [10]. It is observed that challenges such as lack of energy sources as a geophysical concern and warming the climate through greenhouse

gas emissions as an environmental concern, along with increased urbanization and urban development are growing and it is daily added to global problems [11].
Therefore this paper examines the interaction between energy consumption and urban development. It should be noted that the amount of energy consumption in different countries is different depending on patterns of their urban development. As a result the different policies and strategies need to meet the challenges in the future.
According to the above mentioned cases, the problem of domestic energy management is too complex. Therefore it is necessary to analyze energy management in urban residences systematically. Thus the present study examines the effects of domestic energy consumption and urban development.

2. Theoretical framework of system dynamics

Demonstrating nonlinear and feedback effects of decision-maker variables in complex systems is very difficult for human. One can predict through a linear relation between variables while this could lead to incorrect decisions. System dynamics are approach to analyze such nonlinear and complex socio-economic systems. To explain system dynamics, there are five basic elements such as system, feedback, flow variables, relevant diagrams and modeling processes.

3. Modeling process

3.1. *Main variables*

The names of model variables are presented in Table 1 to create a dynamic model.

Table 1. Main variables.

Variables
Energy consumption, average consumption per household, total energy consumption per household, level of energy production, total cost of energy production for domestic applications, budget, allocation of budget to raise the awareness, invest to increase awareness, amount of energy consumption by buying efficient devices, bill of energy consumption per household, decrease energy consumption by modifying consumer patterns, municipal fund, urban development, population, residences, air pollution, green spaces, cost paid by energy consumption.

R1. Reinforcing loop for government budget:

Figure 1 shows that as the government budget increases, its percentage to raise the level of public culture and awareness increase too and government is ready to invest more. Instead, high the level of public awareness, their consumer patterns varied and they become more mature, on the other hand they desire to buy efficient consumer devices according to their financial capacity and because of a time distance, efficiency of energy consumption increases. It can be observed that the budget and level of energy consumption in Iran has a bilateral relationship.

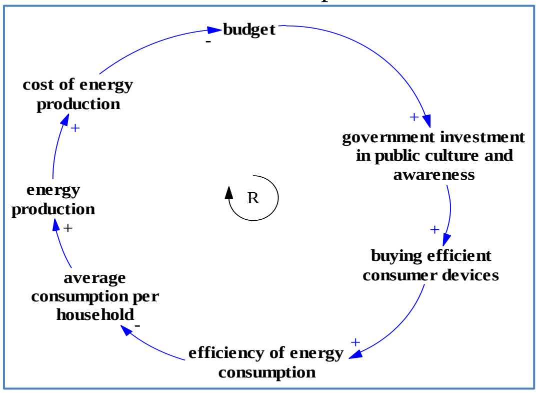

Figure 1. Reinforcing feedback loop for government budget.

B1. Balancing loop for energy consumption

Figure 2 shows that as average energy consumption increases, it leads to increase bill and through time distance causes to reduce the energy consumption. Since high energy bill is considered as an economic challenge for households, they forced to modify their consumer patterns to cope with these challenges. Thus high energy bill plays a balance role in reducing consumption.

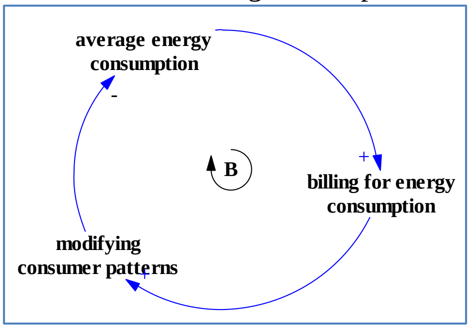

Figure 2. Balancing feedback loop for energy consumption.

B2. *Balancing feedback loop for urban development*

According to Figure 3, as the government budget increases, municipal budget also increases and it leads to develop more because cities need enough budgets to implement their programs. When a city develops, its population increases because residents of rural and other areas immigrate to developing cities and this leads to reduce the mortality rate and increase medical and health care. In addition pregnancy rate because of high education reduces but the population in urban areas has a direct relationship with the rate of development.

High population causes to increase rate of construction in the city, which increases energy consumption. This increases the difference between energy supply and demand and government had to produce more energy so it decrease the government budget and affects negatively on urban development.

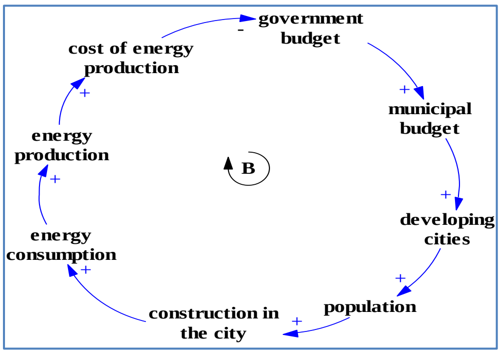

Figure 3. Balancing feedback loop for urban development.

R2. Reinforcing loop for pollution reduction

According to Figure 4, high urban development, greater the amount of green spaces will be because the green space is considered as one of the criteria to estimate the rate of development. By increasing green spaces, air pollution reduces thus pollution reduction is one of the criteria to increase urban development.

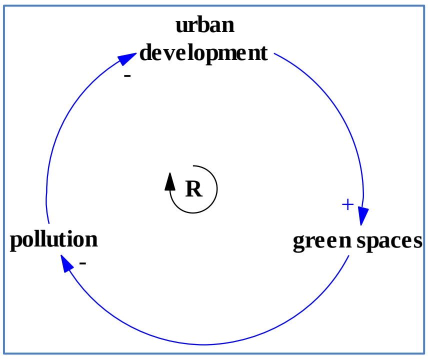

Figure 4. Reinforcing feedback loop for pollution reduction.

B3. Balancing loop for urban development and air pollution

Figure 5 shows that as urban development increases, population and the number of residences increase, so the level of energy production and consumption increases. Since domestic energy production such as electricity, oil and gas depends on fossil fuels, more energy production leads to increase pollution.

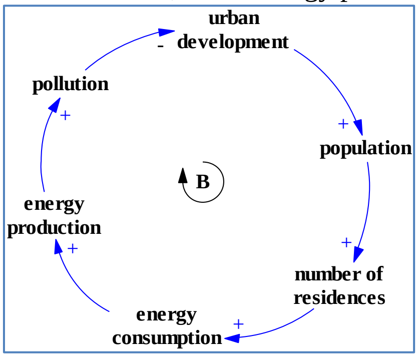

Figure 5. Balancing feedback loop for urban development and air pollution.

R3. Reinforcing loop for Urban Development and budget

Figure 6 shows that as government budget increases, the municipal budget will increase too and this leads to develop more urban areas. When a city develops, the number of residences and energy consumption increase. By increasing energy consumption, cost of bill paid by households will increase so that it leads to increase the government revenues and budget.

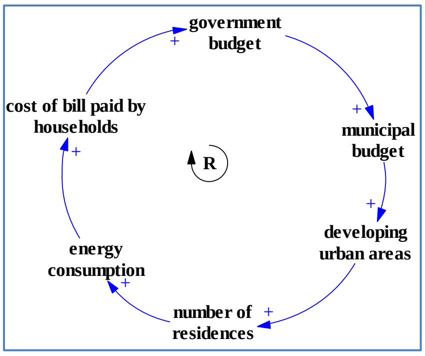

Figure 6. reinforcing feedback loop for urban development and Budget.

3.2. Modeling flow diagram

According to the causal diagram presented in the previous section, flow diagram shows the impact of domestic energy consumption on urban development. Measurement for time variable is year. This model is implemented using software Vensim. It should be noted that this model was simulated for a

100-year period from 2011. For the purpose of building model and decision-making, levels of budget, urban development, population as well as residences were determined that after the simulation stage, the behavior of these variables were analyzed. We defined 4 levels in the model including Government budget, Developing urban, Population and Number of residences.

4. Model simulation

By using dynamic model and relations between variables, the model was simulated and results were analyzed based on the predetermined levels. Figure 7 shows that urban development increases for a 100-years period. In contrast budget decreases initially and then increases. It happens because of high urban development and low budget and since the interests is obtained by urban development, revenues increase relative to the cost and it leads to increase the budget (according to reinforcing loops in the model). Given that urban development process rapidly progresses and then slows down and desires to equivalent level therefore budget reaches normal condition and fluctuates around it. (According to equivalent loops embedded in model). Urban development leads to increase population and consequently, residences increase too (according to causal relationships in the model).

5. Testing dynamic model performance

Based on the relationships shown in the attachment, the relationships among model variables, initial and fixed values of problem were defined. Different tests were used to verify the simulated model:
Testing adequacy scope focuses on adequacy of parameters and causal loops based on the purpose, which this problem by modeling, eliciting the results and focus on model framework was verified.
Testing compatibility of units emphasizes their homogeneity and it was verified based on matching all units by unit Cheque option in Vensim software.
The cumulative error focuses on the lack of sensitivity relative to time scale, that is, if the measurement of time equals to a year, the similar results can be obtained by changing it to 6 months. The test was conducted on the model and results were entirely consistent with previous results. For example, urban development is presented in Figure 8.

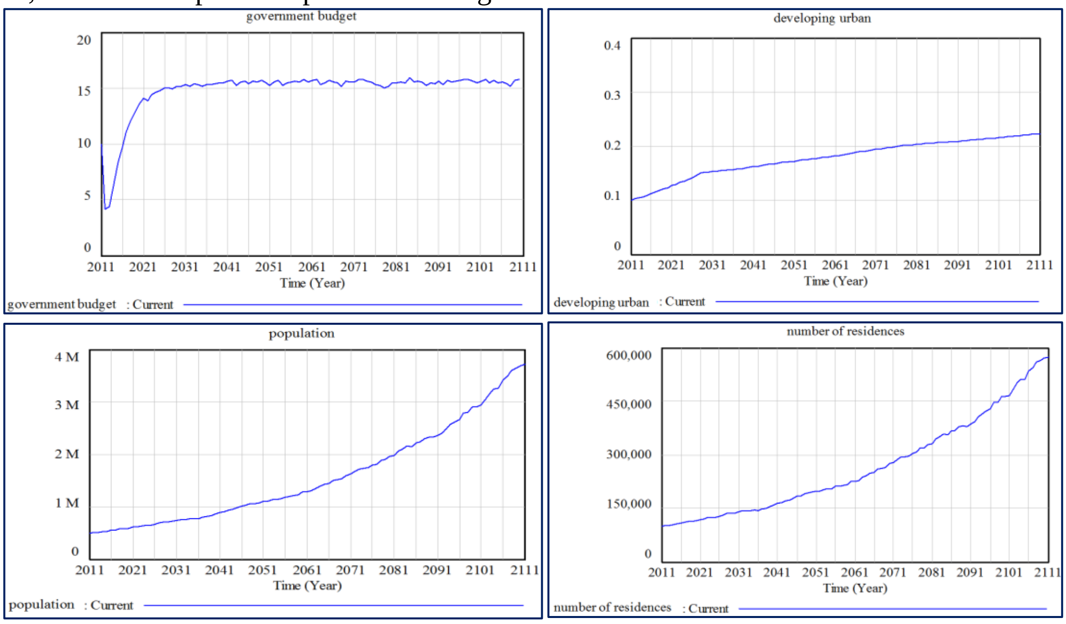

Figure 7. levels of Behavior during 100 years.

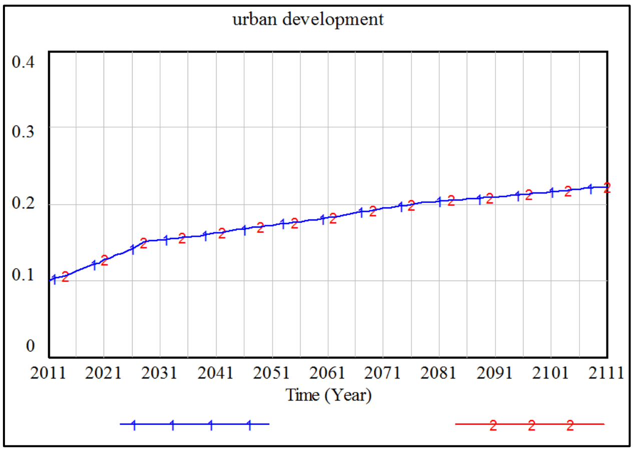

Figure 8. Cumulative error on the urban development variable.

Structure assessment determines compatibility of model behavior with its structure. It is necessary that variables behavior in a simulated model with negative feedback must be purposeful. Figure 5 shows that the slope of the urban development process slow down over time and has a purposeful behavior.
Boundary conditions focus on model resistance, that is, model must show the expected behavior under the conditions of changing systems and input values. Model was verified in terms of boundary conditions.
To perform this test, the "percentage of budget awarded to the city" under boundary conditions 0 was tested and their results on the urban development were considered. It is expected that the urban development should be reached zero over time when government does not allocate fund to the city. The results are shown in Figure 9.

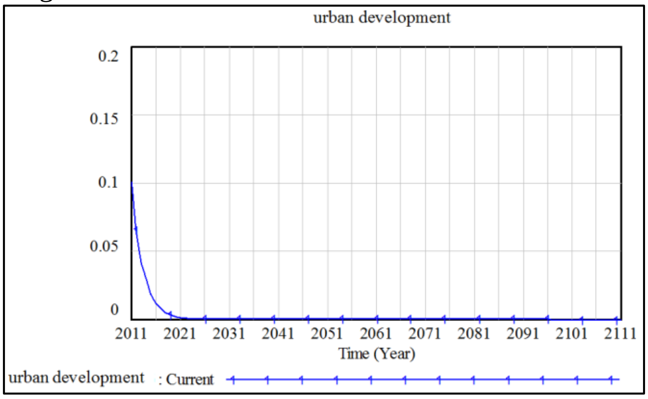

Figure 9. Behavior of urban development in boundary conditions 0.

6. Scenarios

After testing the model performance, dynamic model was evaluated under the different scenarios and the best scenario was selected. In regard to limited resources and the types of policies, the model needs to be done such a way that it shows the most effective performance to develop urban areas.

These 3 scenarios are simulated as follows:

Scenario 1: this scenario called "high allocation of budget without growing green space" focuses on issue of allocation of budget, but it does not include growing green space. Thus this scenario increases "rate of the budget awarded to the city "by 25 %.
Scenario 2: this scenario called "high growth of green space by allocating low budget" focuses on green space, but the allocation of budget will not increase so this scenario improves "rate of green space growth in terms of urban development" by 20%.

Scenario 3: this scenario called the "moderate allocation of the budget with low growth of green space" focuses on both of budget and green space. Thus this scenario improves "percent of the budget allocated to city" and "the rate of green space growth in terms of urban development" by 10 % respectively. The results of each scenario for urban development are as follows:

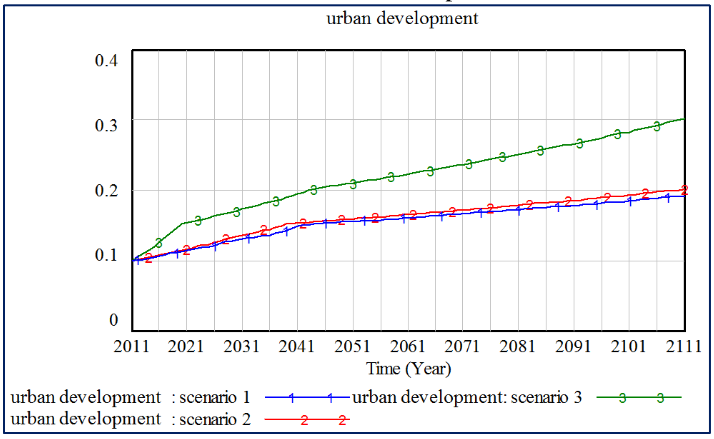

Figure 10. Urban development process under various scenarios.

Figure 10 shows that among three scenarios, the scenario 3 "moderate allocation from the budget with low growth of green space" is better than the other two scenarios.

7. Conclusion

Deeply real improvements in business thinking and practice emerge when managers are responsibility for modeling systems in functional areas. This should be based on personal involvement of managers in the development of a system perspective and define the goals, ways to achieve and success criteria in applying the methods. Given that dynamic system is one of the most widely used method in complex problems, this paper tries to examine the interaction between urban development and energy consumption using causal loops and flow diagram. Finally, the suitable strategies for urban development are proposed by model simulation and different scenarios. Among these scenarios, senario3 "moderate allocation of the budget with low growth of green space" is better than the other scenario. It is showed that that the high allocation of budget without growing green space and vice versa does not affect on urban development and managers need to focus on both of them equally and if necessary, they continue to work more. This model provides the important advantages:
Considering the temporal dimension between cause and effect. Time distance between the cause and effect was considered through delay.
Do analysis "what happens- if". This will reduce the risk of action plans before implementing. In this model, three scenarios were examined and analyzed and then the best one was selected.
Areas could be considered for future research:
It is necessary to be discussed more detail in further research to improve and develop relations and the relevant equations.
More simulations implemented by different policies under various scenarios and analyze the sensitivity of their results can provide more accurate conclusions.

8. References

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