Modeling Sustainability of Renewable Energies in Rural Areas: A Case Study for Iran

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Abstract

In this paper, we have developed a simple system dynamics model to put forward a perspective for explaining the consumer behavior in energy sector and addressing the obstacles facing the development of new energy systems and their sustainability in rural areas of Iran. In our model, we have presented a mechanism, by which cognitive personal concerns of consumers transforms into behavioral outcomes in rustic society, which was not discussed before this paper. Typically, it is presumed that increasing traditional alternative energy prices and influencing social mind by advertisement and publicity leads to people's inclination to renewable energies. We observed that in Iran, as the alternative prices are low due to presence of subsidy, the two aforementioned policies shall be implemented collectively and the more effective factor here is price. Furthermore, we have tested the effects of investment on individual's expertise by education and the results are portrayed. A conventional opinion[1] *suggests improvement by revenue from surplus production for consumers; however, we have proven it fallacious. Although we have done our utmost to cover the major elements while trying to save simplicity for developing our model, further research might be necessary to make any ambiguities clear.*

Keywords: Sustainability, Energy Models, Personal Concern, Tendency, Knowledge for Use, Environmental Conditions

I. Introduction

Statistics reveal that more than two billion of the world's rural population is deprived of common modern energies like electricity. The fossil fuel utilization is still common, spreads poverty among this population, and endangers the environment and people's health. Thus paying attention to energy consumption patterns and sustainability of new patterns in rural areas might be of major importance for policy-makers. Hence, we have put our focus in this paper on energy consumption in rural areas of Iran. Besides, as an instance, in Iran even in rural areas where modern energies are accessible; nearly households consume 10 percent of total energy, which counts for 82 million gallons of oil, which is a significant amount. As a result, if a shift can be managed in rural energy consumption

[1] This is a common belief among government authorities and policy-makers

patterns to increase the attraction to renewable energies, great improvements in economic and environmental conditions will take place. Therefore developing a model to address the policies for this change in energy consumption patterns and sustainability of new energies is critical. Types of energies consumed in rural areas are highly correlated with the culture and economy of these regions. For analyzing various consequences of occurrence of any change in rural energy consumption patterns, and reaching a favorable output for decision-making, some powerful technique is needed. Energy models are powerful means for simulating, analyzing and offering useful recommendations for optimal energy management. The major research done on energy models in the past three decades can be classified into six groups: *Energy Planning Models, Energy Supply-Demand Models, Forecasting Models, Renewable Energy Models, Emission Reduction Models and Optimization Models*.

Energy Planning Models are integrated models linking both commercial and renewable energy sources. A simple model developed by Peter (Peter 1977) addressed the economic feasibility of solar energy for heating systems or photovoltaic energy transformation. Another model was built (Machete 1977) which sought for substitution of primary energies. The social efficiency, literacy and mineral Resources were the main variables of this model. In 1983, a dynamic model (Ambrosone 1983) was developed for the thermal heat energy management of buildings. Another project was carried out in 1987, when George Hsu et al. presented the *integrated energy-planning model* using a multi-objective programming technique linked with traditional Leontief input-output model. Labor, gross domestic product, accessibility of resources, inter-industry interactions and sectoral capacity bounds were the variables considered in building this model. In 1988, Sultan Hafeez Rahman formulated an econometric energy-economy simulation model for energy policy studies for a wide range of developing countries. The variables used in the model were GDP and investment. In addition, the model was used for long-term energy demand forecasting for India (Sultan H. Rahman 1988). Certain important issues like correlation between energy consumption and national revenues and living standards in developing countries, were taken into account for energy policy-making in those countries in a model presented in 1990 (Nastarjan 1990). In this research, also the particular role of electricity in end-use and the role of renewable energy resources for energy supply to developing countries like India were addressed. In 1992, an evaluation method for assessing alternative energies in Taiwan was proposed (Gwo-Hshiung Tzeng 1992). In this method, alternatives for future energy systems were chosen from both traditional and renewable energies like wind, solar and bio-fuel energies. Bala Malik et al.

(1994) described an integrated energy system planning approach for Wardha district in Maharashtra, a state in India for the year 2000. In this paper, an optimal combination of traditional and new energies by aid of linear programming models was also presented. Benefits and needs for transferring the technology of renewable energies to developing countries were discussed by Able-Thomas (1996). The author also discussed various models for transmitting technologies of renewable energies to developing countries. In 1999, for the first time GIS tool (Geographic Information System) was used for modeling renewable energies (Bent Sorensen-Peter Meibom 1999). This model is now applied to several scenarios related to renewable energies and is used as a general means for modeling and planning in energy systems. Finally In 2003, a decision-making multi-criteria methodology for evaluating an executive plan for transmitting renewable energies to rural areas was developed (Beccali 2003). This methodology assists the decision-maker to choose the most appropriate renewable technology, regarding his/her purpose and local potentials.

Energy Supply-Demand Models, Demand Models and Supply Models are widely discussed by several authors. In 1987, a comprehensive model for energy supply and demand in the state of Illinois was introduced (Charles and Mark 1987). In 1990, a linear multiple regression energy demand forecasting model was designed for presenting the energy requirements in rural Nepal (Kamal Rijal et al. 1990) . In developing countries, the major part of energy demand and consumption goes to households. An energy demand-supply model for developing countries based on wood resources in Nepal was suggested in 1993 (Vishwa B. Amatya 1993). 'This model was constructed based on an end-use/process analysis approach, capable of simulating scenarios, could to address issues of increasing traditional energy-demand, sustainable supply capacity of the existing energy resources, potential for development of new and renewable energy resources and technology'. In the same year, an optimized linear model for energy demand-supply for forecasting and inspecting energy system for a 800 village in north China was presented (Fang Zhen 1993). In 1997 the dynamic model of supply and demand forecasting for rural energies regarding its impact on global warming was built (Bala 1997). The output of this model was employed in the LEAP model (Long-range Energy Alternative Planning). Another similar dynamic model associated with energy and environmental concerns was developed by aid of computer in 2003 to address the demand and supply of energy in Bangladesh and its link with global warming.

Forecasting Models are configured by different variables like population, revenue, price and technology. By analyzing these models, one might be able to find out about the patterns of energy distribution. These models are categorized under two major groups: commercial energy models and renewable energy models. The major portion of the former comprises of Fossil fuels and the latter includes solar energy, wind and bio-fuels as reliable and accessible renewable energy resources. These models are weakly related to our work, thus, here we do not go through them any further.

Optimization Models' Formulation of an allocation model is of great help for allocating renewable energy sources to rural areas for meeting future needs. A linear programming model was proposed in 1985, which sought for marginal cost optimization based on environmental restrictions (Ellis 1985). In 1987, a multi-purpose linear programming model with a dynamic optimization for analyzing renewable energy policy-making was developed for a state in India (Das 1987). The mathematical programming energy-economy-environment (MPEEE) was suggested in 1992 (Suganthi L. and Jagadeesan T.R 1992). This model was focused on maximizing the GNP/energy ratio based on environmental constraints so that it might meet the energy needs of India in 2010. In addition, *Renewable Energy Models, Emission Reduction Models* were studied but the more relevant models were the four types described so far.

Based on what was reviewed here, the critical role of renewable energies in policy-making cannot be neglected. Furthermore, the main concern of authors whose work was reviewed was not particularly the issues of rural energy systems until now. In addition, most of the above-mentioned models are non-dynamic; they analyze problems with a static attitude and they normally do not take into account the impact of feedbacks. The complexity of socio-economic systems can be a result of multitude of variables or the large number of decision-making loops in the system, which cause higher order non-linear equations that are tremendously exhausting to solve without dynamic modeling. As energy models for rural areas are usually very complicated, employing dynamic modeling for energy systems might seem to be the most appropriate solution. Accordingly, in this research we have chosen this method.

Regarding this literature review, one might think of the need for developing a comprehensive and dynamic perspective for the complex and multi-factor energy system of rural areas. Besides, in some recent experiences in Iran, a few projects were carried out to replace the traditional energies with renewable ones, but most of them were unsuccessful. In this paper, we will obtain a dynamic approach to assess various dimensions of sustainability for renewable energies.

In this paper, we have initially developed a dynamic model to assess the sustainability for renewable energy consumption patterns in rural areas of Iran. Then in the first section, we have presented the model structure and its elements and four policies for reaching sustainable energy patterns were tested. We have discussed the results and put forth a few recommendations for better implementation of projects for development of renewable energies and more consumption sustainability.

II. Model Structure

People make cost-benefit comparisons for their everyday decision-making, even though for many objects and behaviors a certain evident cost does not exist. Normally they form a perception of the cost and price of some good or a certain act or behavior. Decision-making and tendency for consuming renewable energies versus traditional kinds is also mainly initiated from cost-benefit evaluations and perception of people of those costs.

Base of our model is on two major variables: *tendency to use renewable energies* and *Environmental Concern*. Tendency to use renewable energies shows the average tendency of society to consume renewable energies. Here we presumed that the tendency based on some social factors, would affect percentage of use of renewable energies. The tendency also influences the personal concern of people to consume renewable energies, which might be because of two reasons: normative effects or prestige and mode that are classified as cognitive effects. When the average tendency increases, each person's concern for using renewable energies will rise and so people will feel some social cost for not using renewable energies. When a person wants to decide whether to choose renewable energies or not and when the personal tendency is being formed, a sum of average real cost of traditional energy and its social costs -by not using renewable energies- would be compared with the cost of consuming renewable energies which comprises initial investments and maintenance costs. An increase in the tendency will increase personal concerns, causing the costs of using non-renewable energies to rise. The rise of this cost versus renewable energy costs will increase the tendency itself. Thus, a positive loop, which shapes the dominant behavior of the model, can be seen here. The loop is demonstrated in exhibit 1.

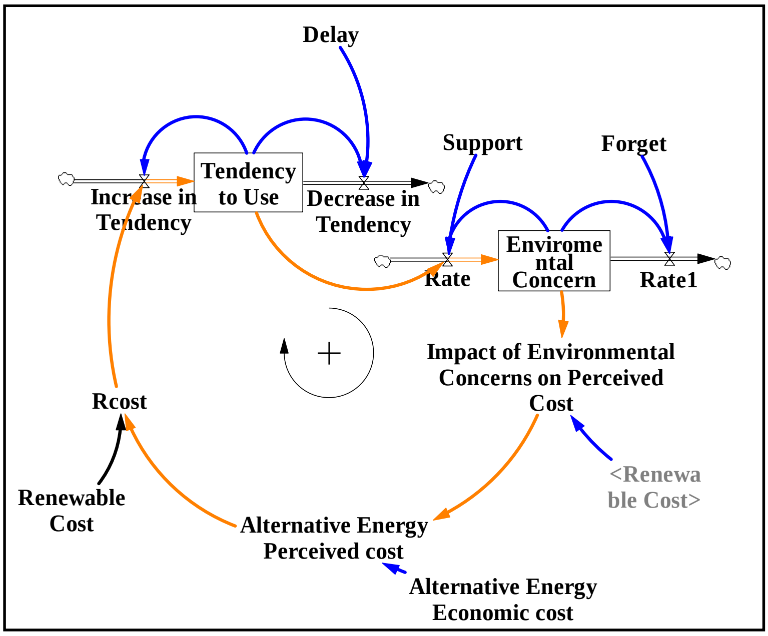

Exhibit 1

Furthermore, an increase in tendency to use renewable energies will raise the percentage of renewable energy consumption and this in turn reduces some factors like pollution, etc. and ameliorates the environmental conditions. Thus, people will face less harm for not consuming renewable energies and this in turn reduces the personal concern and social tendency to use renewable energies. This forms a negative loop that has an inherent delay in the process of transformation of personal concerns into social tendency. This provides a damping of the first positive loop by the negative one hence producing an s-shaped behavior, which contains overshoot due to existence of delay. The two loops are illustrated together in exhibit 2.

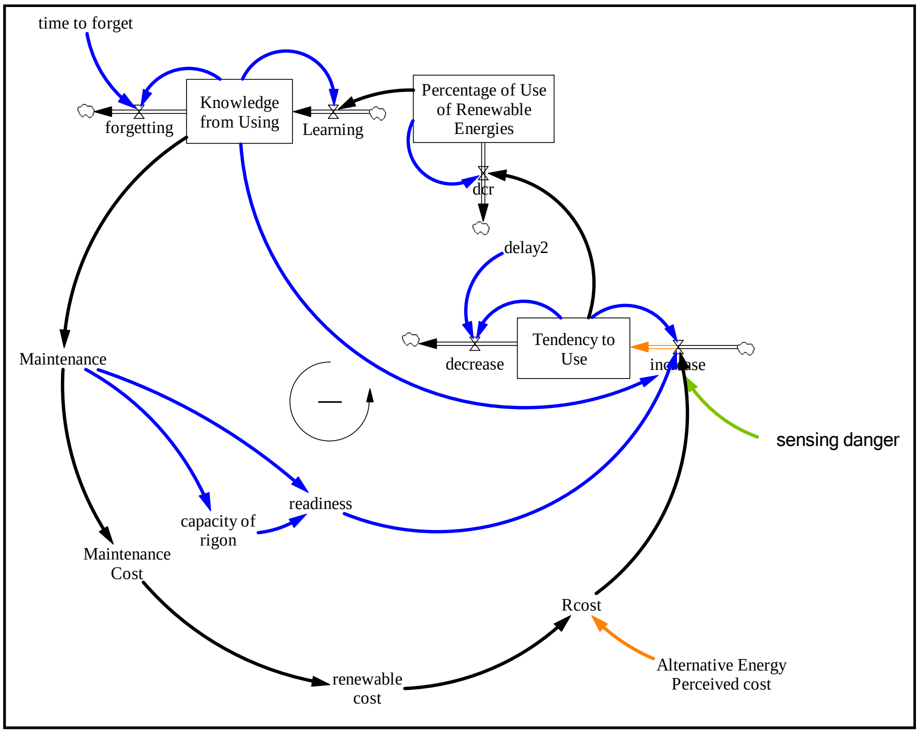

Exhibit 2

By only regarding these two major loops, we might anticipate that there always exists a steady state after the implementation of any renewable energy infrastructure, which by experience is proved wrong. This might result from lack of proper knowledge and know-how of using renewable energies in rural regions[2]. By mere gradual augmentation in percentage of use of renewable energies, in a *learning-by-doing* [3] process, the extent of knowledge of people of these areas for using renewable energies and related devices and equipments will enlarge and thus the tendency of people will increase. Here we have a positive learning loop that is shown in exhibit 3.

[2] For instance, a public lavatory using biomass encountered serious problems and got closed only one year after foundation in one of Iranian northern provinces just thanks to lack of this proper knowledge of using renewable energy resources in rural areas in that province.

[3] The purest example of learning from direct experience (learning by doing) is found in the effects of cumulated production and user experience on productivity in manufacturing (levitt 1988).

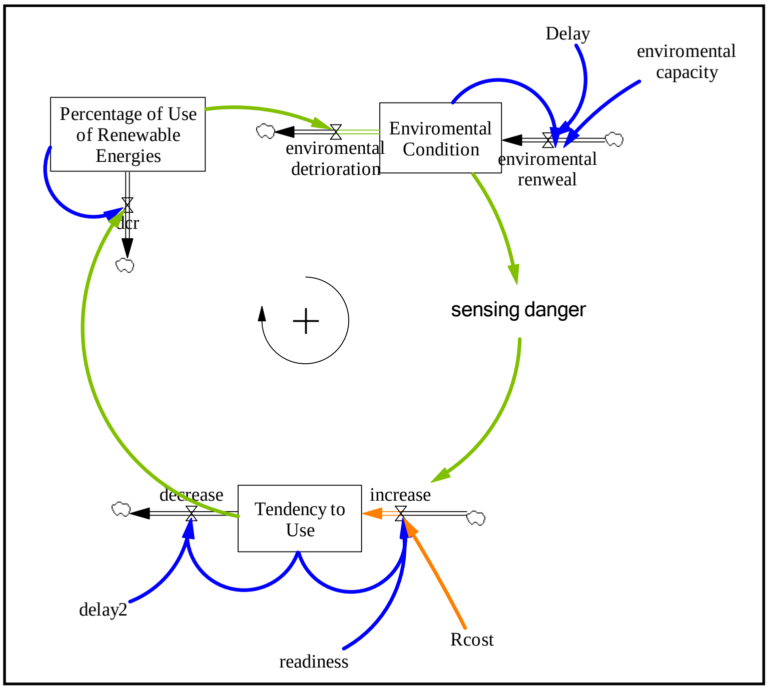

Exhibit 3

Moreover, accumulated knowledge of use will increase the efficiency of employing certain technologies by learning curves, therefore reducing maintenance and service costs and the total costs of consuming renewable energies, hence making a better choice for consumers out of renewable energies versus traditional energies.

Based on the model it can be observed that firstly people become inclined to use renewable energies somehow. For example, when in Iran some agents from government install the equipments, the tendency to use renewable energies start to rise and thus the percentage of use starts to increase. Accordingly, the knowledge of use also starts to expand in a certain period. Nevertheless, as it takes a while in order that the effects of not using renewable energies will inform people of low environmental conditions and because of low rate of increase in tendency to use renewable energies due to time lag in learning of people by using, personal concern would rise only gradually.

The slowly increasing personal concern would cause the perceived cost of traditional energies to be less than the cost of renewable energy. In addition, individuals decide based on relative prices and this affects their tendency to use renewable energies. So the percentage of use of renewable energies decreases sharply and if this percentage reaches zero, even if the personal concern starts to rise, unless the knowledge of use or maintenance can be conveyed to consumers, the tendency will not face an increase.

On the other hand, reduction in percentage of use of renewable energies will result in major increases in its cost and so the relative cost, upon which the individuals decide for consuming, will increase and this enhances the effect of personal concern on tendency reduction. The above-mentioned process can be evidently seen in the projects carried out so far in rural areas of Iran. Although the government has put huge amounts of expenses and expertise through sustaining renewable energy infrastructures in rural areas, still people are inclined to consume traditional alternatives instead.

III. Policies and Insights

Regarding what we have mentioned so far, a few policies seem to be appropriate for this model, which are as follows:

- Cultural support policy
- Alternative energy price increasing
- Enrichment of the knowledge of consumers

Cultural support policy: one policy can be the cultural support of government or any other concerning firm by any advertisements or cultural programs via television, schools, etc. This support has been illustrated on the model and affects the rate of increase of personal concern. To implement this policy we added a constant coefficient named *governmental support*, which indicates cultural support. The results before and after addition of this coefficient are shown in exhibit 4.

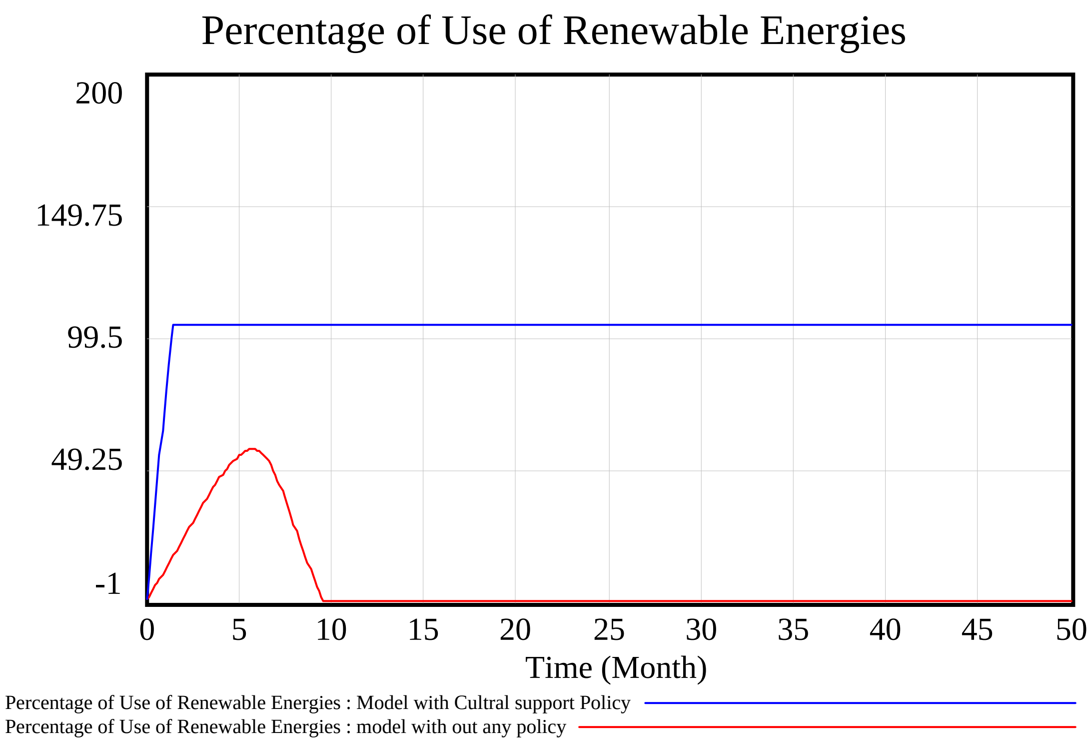

Exhibit 4: When we implement this policy, we can see that percentage of use can be sustainable

Alternative energy price increasing: another policy can be increasing the price of alternative traditional energies. As in Iran, this price due to subsidy policies is usually really low, it seems that the cultural policy mentioned before might not be effective enough without setting price policies. Besides any changes in tariffs for alternative energy, prices could lead to unfavorable social consequences. Performing this policy was accomplished by applying a step function to *alternative energy economic cost* that is presumed to be an average of traditional alternative energies. The results are shown in exhibit 5.

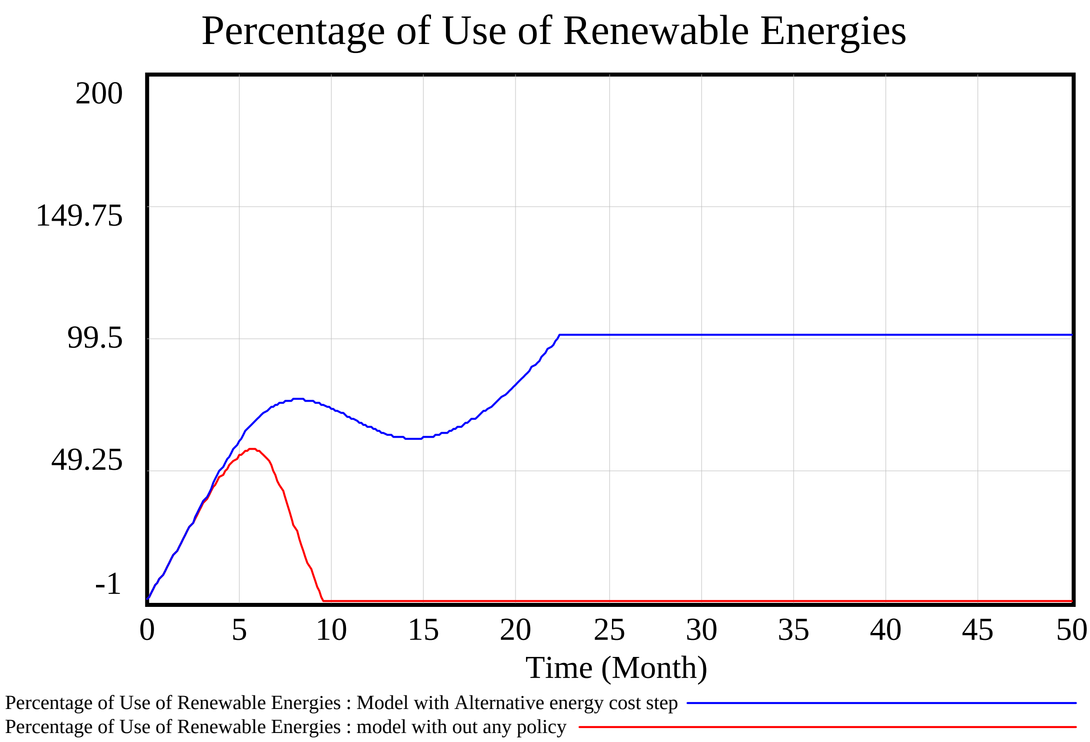

Exhibit 5: When we implement this policy, we can see that percentage of use can be sustainable

Enrichment of the knowledge of consumers: in addition, learning in our model is performed by the mechanism of learning by doing. Hence, if we can increase the individuals' expertise in using renewable energy, using equipments and dealing with breakdowns, the maintenance costs will fall and thus reduce the renewable energy costs versus alternatives. This in turn will diminish the effect of low rate of increase of concern. Here we have added a variable named *knowledge enrichment* that influences the rate of increase in knowledge for using renewable energies. A step function was applied to this variable to show an endeavor by government to enhance consumers' knowledge. The results are as demonstrated in exhibit 6.

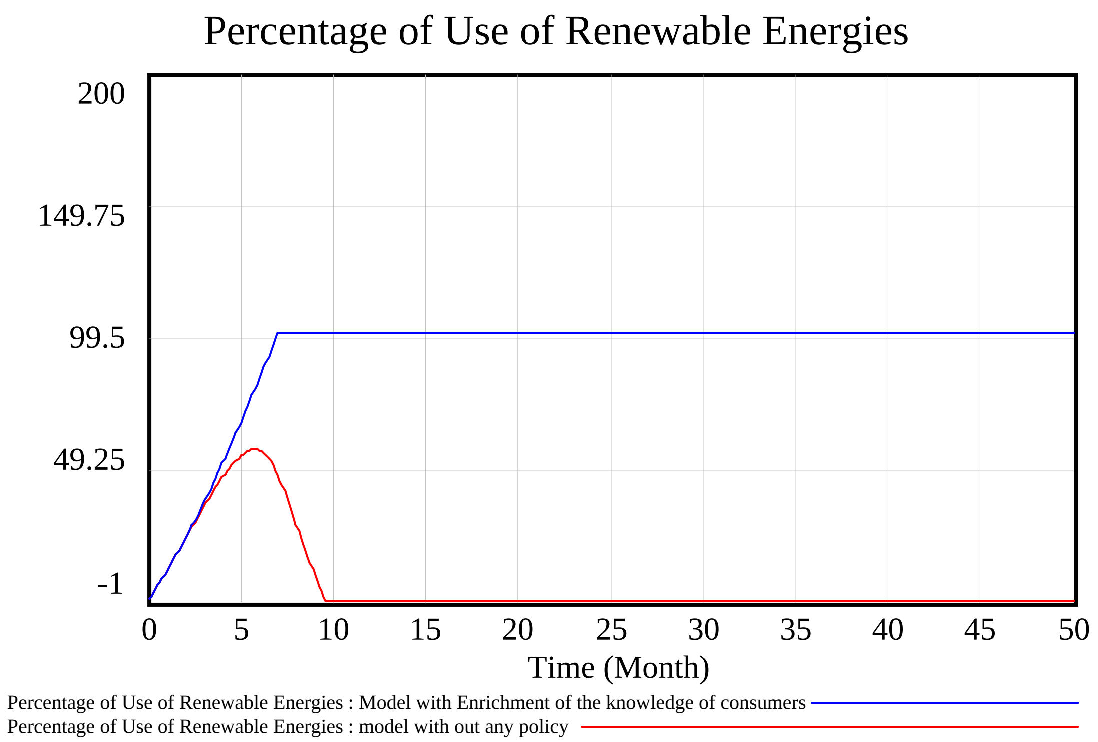

Exhibit 6: When we implement this policy, we can see that percentage of use can be sustainable

Common well-known opinion in Iranian government is to think that the policy of encouraging people to produce renewable energy by buying the surplus will reduce the relative cost and thus expands renewable energy usage in rural areas. We performed this policy in our model to verify its validity and we will demonstrate the results. This policy was implemented on the model by adding a variable named *capacity of rural renewable energy production* by which we measured the rural renewable energy production. Then the production was compared to rural energy consumption and as illustrated in exhibit 7, the results showed that there is little difference between rural production and consumption. Therefore, no surplus exists and people would not benefit from this policy for improvement.

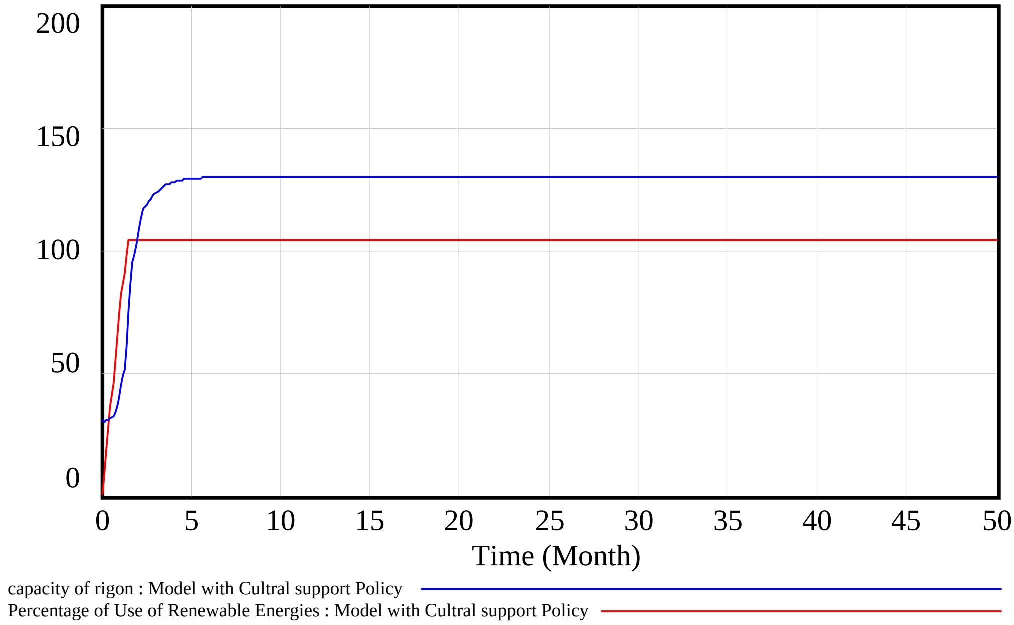

Exhibit 6: When we implement this policy, we can see that percentage of use can be sustainable

IV. Conclusion and Recommendations for Further Research

The results of our research might be handy to policy-makers and helps implementing better projects for more sustainable renewable energy systems. The importance of the sustainability issue seems critical especially in Iran as the government has carried out a myriad of projects to establish renewable energy consumption patterns in rural areas and always has failed. By noticing the effects of price policies and knowledge transfer to rural households, the government might be able to reach a convenient reduction in its expenditure for renewable energy systems implementation.

As mentioned before, we have tried our best to consider all major elements as well as saving simplicity of the model. For instance, some of the related elements such as air pollution, deforesting, and any other hazardous threat to the environment have been put into a category named *Environmental Conditions* or for example, *Knowledge from Using* is a stock variable that may represent several learning processes. Future research may include generating the model using less integrated variables. In other words, the variables listed above each might individually be inserted into the model, which will result in creating a more complicated and of course more accurate model.

Further research might also include generating a similar model for urban areas, which usually possess more complicated socio-economic systems than rural areas in Iran.

V. Acknowledgements

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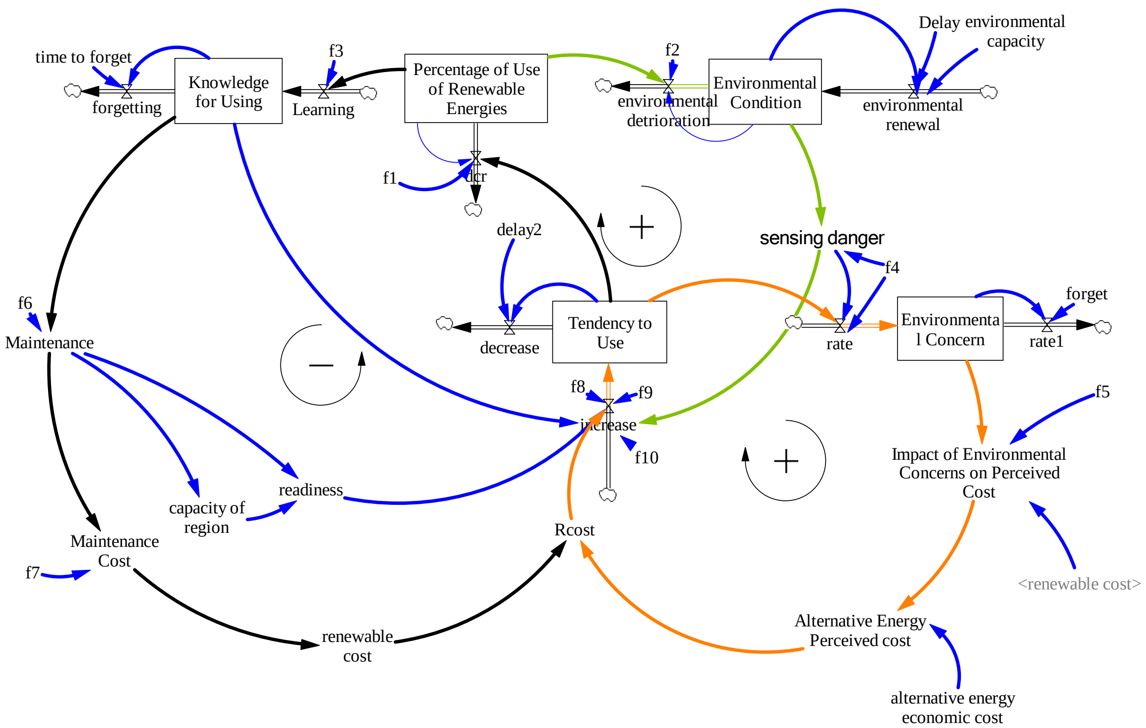
Appendix1. Structure of the integrated Model



Appendix2. Equations of the model

- alternative energy economic cost=100
- Alternative Energy Perceived cost=alternative energy economic cost+Impact of Environmental Concerns on Perceived Cost
- capacity of region=30+Maintenance
- dcr=IF THEN ELSE(Percentage of Use of Renewable Energies<0, 0, f1(Tendency to Use)*100)*IF THEN ELSE(Percentage of Use of Renewable Energies>100, 0, 1)
- decrease=Tendency to Use/delay2
- Delay=50
- delay2=5
- environmental capacity=100
- Environmental Concern= INTEG (rate-rate1,20)
- Environmental Condition= INTEG (environmental renewal-environmental deterioration,80)
- Environmental deterioration=IF THEN ELSE(Environmental Condition<0, 0, f2(1-Percentage of Use of Renewable Energies))
- Environmental renewal=(environmental capacity-Environmental Condition)/Delay
- f1([(0,-0.4)-(100,1)],(0,-0.2),(20,0),(100,1))
- f10([(0,0)-(1,1)],(0,0),(0.207951,0.0657895),(0.391437,0.245614),(0.489297,0.491228),(0.614679,0.714912),(0.788991,0.890351),(1,1))
- f2([(0,0)-(100,10)],(0,0),(11.315,0.438596),(18.0428,0.877193),(30.8869,1.88596),(41.2844,3.33333),(50.1529,4.91228),(61.1621,7.54386),(68.1957,8.85965),(75.841,9.47368),(84.4037,9.69298),(100,10))
- f3([(0,0)-(100,100)],(0,0),(14.0673,3.94737),(25.3823,15.3509),(41.2844,32.0175),(50,50),(58.7156,64.9123),(70.3364,80.7018),(83.4862,90.7895),(100,100))
- f4([(0,0)-(100,1)],(0,1),(12.2324,0.964912),(22.63,0.938596),(32.1101,0.868421),(41.2844,0.745614),(46.4832,0.640351),(49.8471,0.5),(54.4342,0.390351),(59.3272,0.289474),(68.5015,0.149123),(78.5933,0.0657895),(87.4618,0.0394737),(100,0))

- f5([(0,0)-(100,1)],(0,0),(15.9021,0.0350877),(29.6636,0.135965),(38.2263,0.254386),(44.6483,0.372807),(50,0.5),(59.0214,0.662281),(67.2783,0.785088),(77.9817,0.907895),(86.2385,0.964912),(100,1))

- f6([(0,0)-(100,100)],(0,0),(10.0917,3.07018),(24.4648,10.0877),(41.896,23.6842),(50,40),(59.0214,57.4561),(62.3853,63.5965),(67.5841,70.614),(80.1223,85.9649),(100,100))

- f7([(0,0)-(100,1)],(0,1),(100,0.1))

- f8([(0,0)-(100,1)],(0,0),(6.42202,0.127193),(17.4312,0.315789),(32.1101,0.434211),(50,0.5),(62.9969,0.570175),(76.4526,0.701754),(87.7676,0.833333),(100,1))

- f9([(0,0)-(1,1)],(0,1),(0.155963,0.951754),(0.281346,0.837719),(0.385321,0.684211),(0.501529,0.504386),(0.565749,0.350877),(0.675841,0.162281),(0.82263,0.0438596),(1,0))

- FINAL TIME =50

- forget=10

- forgetting=Knowledge for Using/time to forget

- Impact of Environmental Concerns on Perceived Cost=f5(Environmental Concern)*renewable cost

- increase=f8(Knowledge for Using)*f8(readiness)*f9(Rcost)*f10(sensing danger)*100000

- INITIAL TIME = 0

- Knowledge for Using= INTEG (Learning-forgetting,1)

- Learning=f3(Percentage of Use of Renewable Energies)

- Maintenance=f6(Knowledge for Using)

- Maintenance Cost=4000*f7(Maintenance)

- one hundred percentage=100

- Percentage of Use of Renewable Energies= INTEG (-dcr,0.01)

- rate=f4(Tendency to Use)*sensing danger

- rate1=Environmental Concern/forget

- Rcost=renewable cost/(Alternative Energy Perceived cost + renewable cost)

- readiness=Maintenance + capacity of region
- renewable cost=Maintenance Cost
- SAVEPER = TIME STEP
- sensing danger=f4(Environmental Condition
- Tendency to Use= INTEG (increase-decrease,10)
- TIME STEP = 0.125
- time to forget=1
- total energy use=1