Sustainable Technology Assessment and Sustainable Scenarios of Techno Social Phenomena*

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Abstract: Sustainable technology can be described as a technological subsystem with marginal or no negative impacts on other technological systems, as well as the environment, the society and the economy. To identify such technologies it is necessary to describe their behavior and their present and future interactions with those systems. Due to social dynamics, a complete assessment to identify sustainable technologies requires a hard systems analysis and a soft system analysis. A hard system analysis is useful to assess the interactions, behavior and characteristics of the technology quantitatively. A soft system analysis is convenient to describe other characteristics and interactions through qualitative and non measurable characteristics. System Dynamics is a useful resource to forecast the behavior of technology related systems for which the hard systems logic is the dominant paradigm. Key variables related to technological assessment subject to system dynamics modeling include population growth, efficiency, energy intensity, release of greenhouse effect gases, and the expansion of risk areas. The selection of indices and variables is determined according to the studied technology. Therefore, a detailed description of the technology is fundamental. In this paper, sustainable technology is briefly described, an example of systems dynamics to forecast quantitative qualities of socio-technological system and conclusions are presented.

Keywords: Sustainable technology; sustainable technology assessment; forecast.

1. Introduction

A sustainable society implies optimal conditions of equality, governance, and a harmonic relationship between human and natural systems. One important human system is technology and all its components, such as institutions, knowledge, and material and immaterial developments. Technology acts as an extension of human activities. The use of any technology is associated with material or immaterial

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negative impacts that are related to intrinsic characteristics of artifacts. At the same time, it has allowed human kind have a better quality of life. In its nature, technology has dual effects: the positive immediate effects such as health or protection; and cumulative negative effects such as waste production and economic disparities. Consequently a sustainable future requires a sustainable technology. In other words, a technology is appropriate for a society if such technology improves the quality of life of a social group without compromising its wellbeing (Dunmade, 2002, p. 464).

A technological system can be characterized through its interaction with society, industry, nature and economy. These characteristics are (Tezanos et al., 1997, p. 76-77):

- Operability;
- Social and environmental impact;
- Social character;
- Social independence on individuals and consequences.

These interactions can be positive or negative according to the context in which the technological system is placed. A sustainable technology can be defined as a one with marginal or no negative impact on subsystems where the technology will be used, built or installed. Therefore, to identify one, its interactions with other related systems, such as social systems, economic systems, the environment and other technological systems must be identified and evaluated.

Technology Assessment is a multidisciplinary procedure in which the potential impacts of a technology within social, economic and environmental circumstances are identified in order to evaluate the sustainability of a technology. Due to the nature of social phenomena, some impacts can be quantified, but other phenomena can only be described by their qualitative properties. Some quantifiable characteristics are population or efficiency. On the other hand, non quantifiable qualities related to techno-social systems include the rejection of new technology, economical allegiances between commercial partners or legal restrictions. Therefore, tools to analyze quantitative and qualitative impacts must be included.

The evaluation of indices can be used to analyze quantitative impacts. System dynamics modeling can be used as a tool to model the evolution of key variables related to sustainable issues within a defined threshold. Some quantitative variables are population and population growth, efficiency, greenhouse effect gasses, and consumption of natural resources.

Shale gas technology was originated in the mid 1980s. It is considered as an alternative to the energy crisis since shale gas deposits imply that the reserves of natural gas are larger than expected. However, the intensive use of water associated with hydraulic fracturing process and some soil mechanics concerns are potential risk associated to the its production.

To comply with the hard system analysis of the technology associated with shale gas, system dynamics methodology was used to build a relatively simple model to forecast the behavior of human, technological and natural subsystems. The model was divided in subsystems of human activity, population and population growth. Productive activities were represented in terms of energy consumption, energy production and a technological index based on efficiency. Public policy on technology was presented as different growth ratios for the use of shale gas technology. The interaction with natural subsystems was mainly represented by release of greenhouse effect gases to the atmosphere. The obtained results were used to evaluate key indices such as energy intensity. The results were used to evaluate the different effects of the use of the technology under different conditions and scenarios. Some recommendations on how to minimize negative impacts of shale gas technology were formulated.

System dynamics or other numerical modeling tools are an important part of any technology assessment tool. The appropriate modeling process should be chosen carefully according the characteristic or behavior to be observed. As any other forecast procedure, the obtained results have a certain degree of uncertainty. The drawn scenarios are not predictions. They are artificial futures useful to identify positive or negative outcomes of present decisions, and helpful to allow us, to establish guidelines to achieve a more sustainable future.

2. Shale Gas

The oil crisis of the 1970s provided the adequate context to seek for alternative sources of energy. The first experimentation to extract shale oil dates back to the early 19th century. The fracking techniques aimed to increase gas and oil production were developed towards the mid 20th century (USDOE, 1993).

Towards the early 1980s, the advent of improved downhole drilling motors and the invention of other necessary supporting equipment, materials, and technologies, made horizontal drilling commercially viable (USDOE, 1993). Mitchell Energy and Development Corporation achieved a commercial large scale shale gas production during the 1980s and 1990s in the Barnett Shale in North Central Texas. By 2005, the Barnett Shale was producing nearly 0.5 trillion cubic feet of gas per year (ibid.). In 2011, the technically recoverable shale gas resources were estimated to be 6622 trillion cubic feet worldwide; US reserves are estimated to be 681 trillion cubic feet; Mexico's reserves are estimated to be 681 trillion cubic feet.

The production of non-conventional energy sources, such as shale oil and gas, has been rapidly increasing. The main driver of this phenomenon is the advanced exhaustion state of the conventional hydrocarbons, the subsoil property rights, the importance of the service industry and its scientific and technologic capacity regarding subsoil science and engineering (Rodríguez-Padilla, 2012). Most consequences of the adoption of shale gas have not been foreseen. Many of these involve technologic, economic and environmental issues. As a consequence to the increasing production of non-conventional energy sources, the price of natural gas has sunken and it is no longer linked to the costs of conventional crude oil. If the current conditions prevail, the US would achieve their energy independence by 2022 (USDOE-EIA, 2011).

Public policy of several governments shows certain preference for the adoption of shale gas as an energy source to fulfill the energetic requirements of the population. On the other hand, some associated risks, such as water consumption, pollution of underground reserves of water, and emission of green house effect gases constitute negative effects of the production of shale gas. Shale gas has the potential to play an important role in the energy production in several countries. At the same time, sustainable conditions are necessary to improve living conditions and better conditions and more solid economic growth. Therefore, it is necessary to assess the sustainability of shale gas to consider the risk of adopting that technology into the production of hydrocarbons in developing economies.

3. Systems Dynamic Model of Shale Gas Production

System dynamics is a powerful tool to model the evolution of quantitative variables involved in a technology assessment. With that purpose, a model based on system dynamics was built to simulate the variables involved in the production of shale gas within the Mexican territory.

The main variables selected for this model are:

- Population;
- Economic growth;
- Growth of the production of shale gas;
- Carbon efficiency; and
- Energy consumption.

These variables are simulated to obtain the evolution of the following indicators:

- Reserve exhaustion threshold;

- GDP;
- Energy Intensity; and
- Emission of green house effect gases associated with shale gas.

The main purpose of this model is to describe the association between population growth, economic growth, and cumulative effects associated with the production of shale gas. And by simulating such dynamics, determine the evolution of main indicators to assess the influence of the use of shale gas in energy consumption, emissions, and exhaustion threshold of the selected technology.

The flow diagram of the production of shale gas is shown in figure 1.

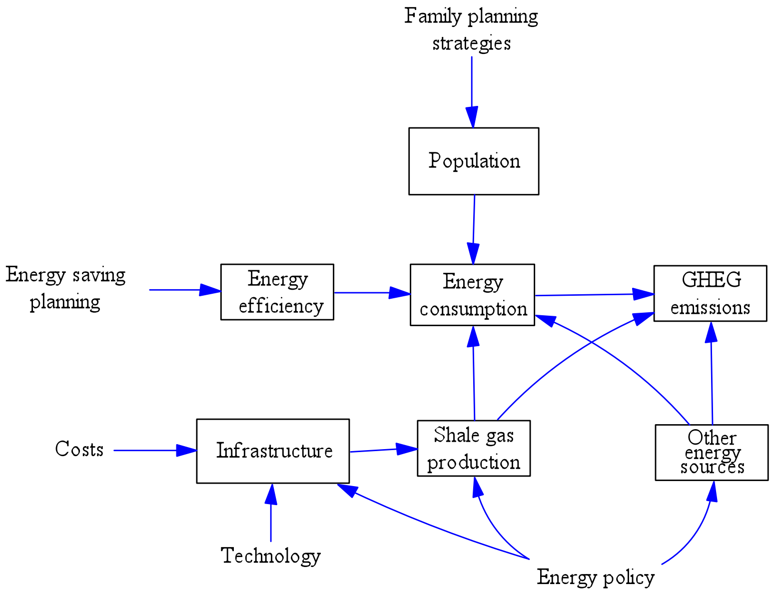

Figure 1. Flow diagram of shale gas production.

The main issues involved in the shale gas production and consumption are population, energy efficiency, technology and public policy on what energy source is favored. Therefore, the model should contain such variables. The shale gas model, using the Vensim notation is shown in Figure 2.

Different scenarios with various growth rates were proposed to compare several development conditions of shale gas production. The GDP growth was set to a constant rate of 2.54%, which is the estimate growth for the Mexican economy according to official data (CEPEP, 2012).

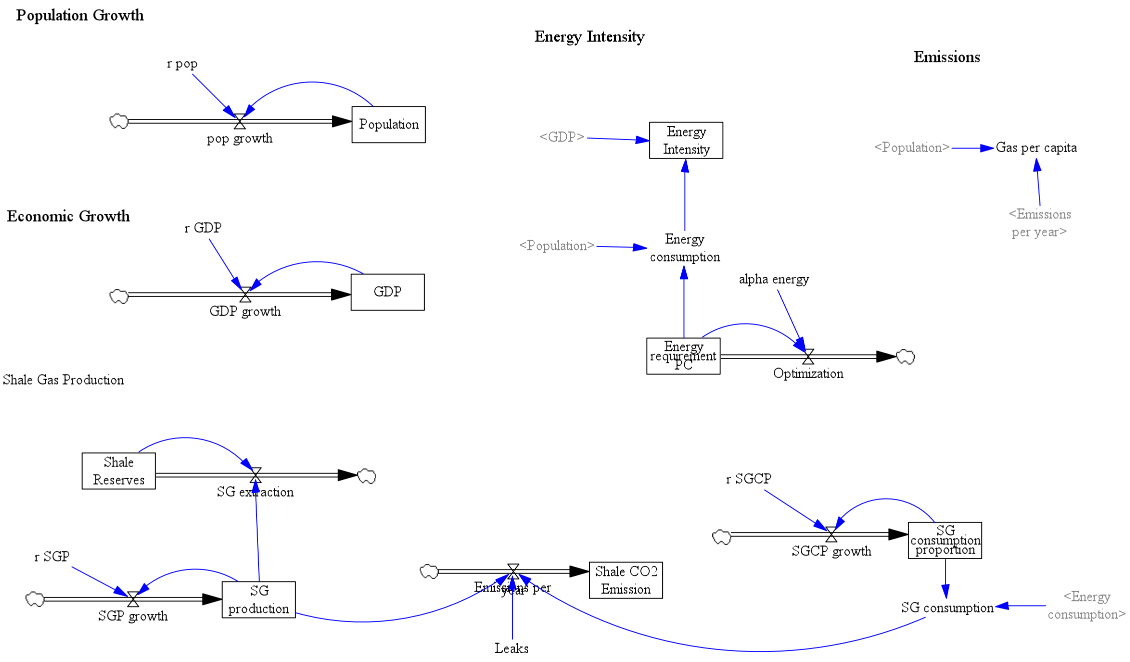

Figure 2. Shale gas production, consumption and emission model.

Using current numbers as reference, other growth rates were proposed to draw the various scenarios. The data used to run the simulations are shown in table 1.

Scenario	Population growth	Efficiency improvmnt (a)	Shale gas production growth rate	Shale gas consumption growth rate	Description
1	1.8 %	-0.1 %	7.9 %	7.9 %	Rates based on current values.
2	1.0%	-0.4%	5.0%	5.0%	Population growth diminished, and maximum efficiency improvement to achieve IPCC B2 scenario. Shale gas production and consumption

					are moderate.
3	1.8%	-0.4%	12.6%	8.0 %	Population growth remains high. Efficiency improvement is maximized. Shale gas production and consumption are maximized.
4	1.2 %	-0.3%	5.0 %	5.0 %	Population growth is moderate. Efficiency improvement is moderate. Shale gas production and consumption moderate
5	1.2 %	-0.3%	12.6%	8.0%	Moderate population growth. Moderate efficiency improvement. Maximized production and consumption of shale gas.

Table 1. Growth rates and efficiency rates.

As initial conditions, the values of energy consumption per capita, population, and GDP value were used. These values are shown in table 2.

Variable	Value	Source
GDP (2011)	1.153 trillion US (x10^{12})	World Bank (2013)
GDP growth rate (2012)	3.30 % (2012) 2.54 % (Average from 1980 to 2012)	CEPEP (2012)
Population (2010)	112 322 757	INEGI (2011)
Population growth (2010)	1.8 % 1.2 %	INEGI (2011) World Bank (2013)
Energy consumption per capita	1.6 tons of oil equivalent (2010) (66.992 GJ)	Economist Intelligence Unit

	1.7 tons of oil equivalent (2015) (71.179 GJ)	(2011)
Hydrocarbons production growth rate (2012)	7.9 %	SENER (2012)
Shale gas production	0 (2011) 1346 x 10^6 cubic feet by 2026 (inercial) (38.11x10^6 m^3, growth rate of 8%) 3279 x 10^6 cubic feet by 2026 (strategic) (92.85x10^6 m^3 growth rate of 12.6%)	SENER (2012)
Methane leakage associated to hydraulic fracking (2011)	3.6 – 7.9 %	Howarth, R.W., Santoro, R., and Ingraffea, A. (2011).

Table 2. Reference values of variables.

4. Results

The scenario graphs and trajectories were compared to the ideal scenario 2, which was simulated using the goals set by the IPCC. The analysis was performed based on the scenario's fulfillment of IPCC goals, rather than absolute numbers.

The curves obtained from the different scenarios and variables are the following:

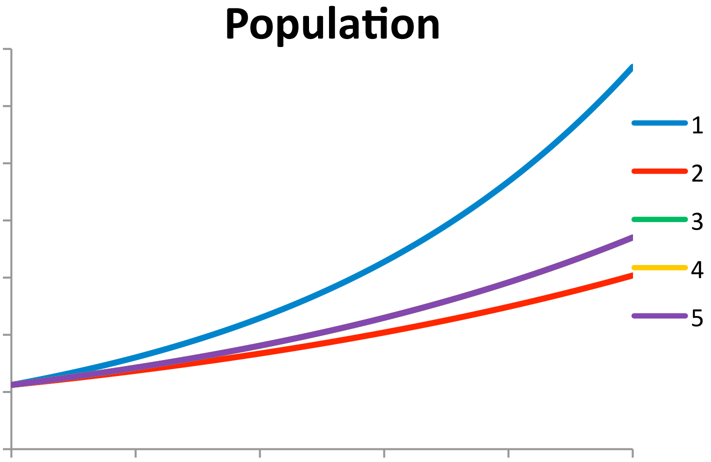

Figure 3. Population variation in the different scenarios. Scenario 3, 4 and 5 are overlapped.

As expected, population dynamics is only sensible to population growth rate. Although in the short term the deviation of the trajectories is small, in the long run, the trajectories show a clear difference.

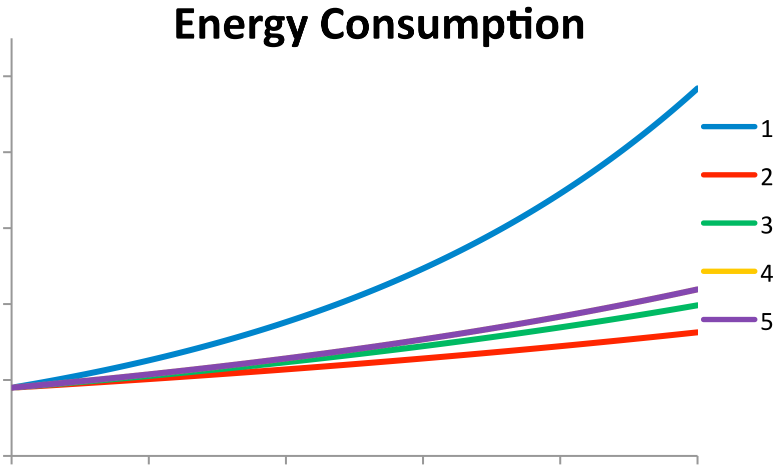

Figure 4. Energy consumption. Scenarios 4 and 5 are overlapped.

For energy consumption, the model is sensible to population growth rate and efficiency improvement rate. As in the population graph, the differences in rates is clear as the simulation pulses number increases.

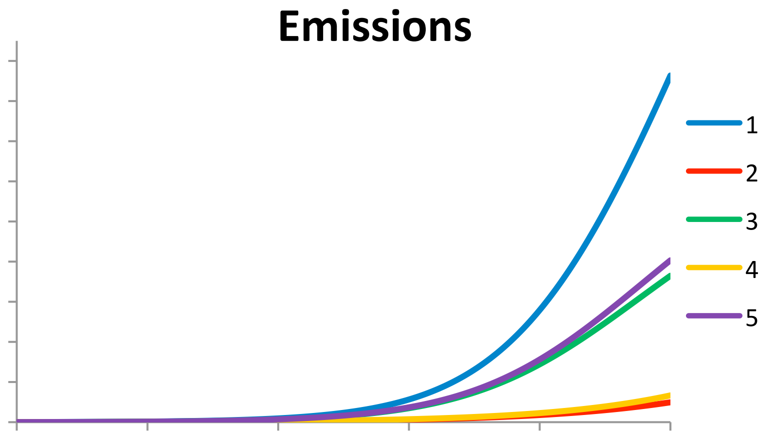

Figure 5. Emissions in CO_2 equivalence.

Emissions are sensible to shale gas production growth rate, population growth and efficiency improvement rate. Scenario 4 is the closest to ideal conditions represented by scenario 2. They have in common the shale gas production growth rate. Efficiency improvement rate is slightly smaller, and population growth is slightly higher. Therefore, that slower expansion rate and better efficiency rates would have a high impact on emissions.

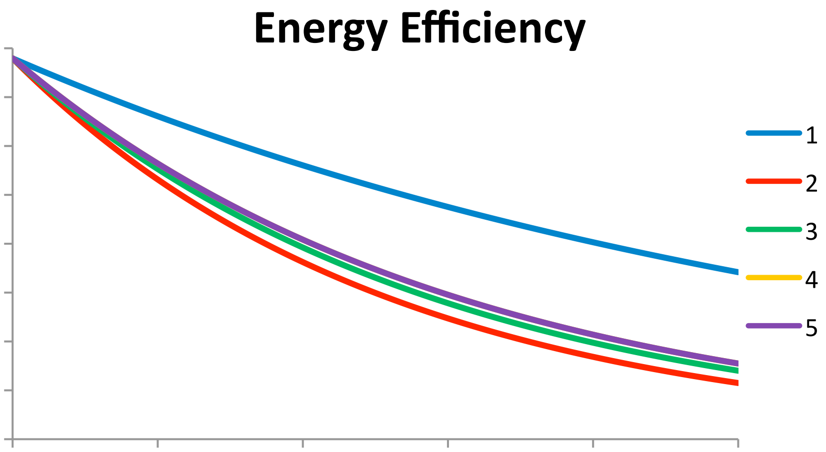

Figure 6. Energy efficiency. Scenarios 4 and 5 are overlapped.

For Energy efficiency, the conditions on scenario 3 are closest to conditions on scenario 2. In this case, energy efficiency is very sensible to efficiency improvement rate. Other factors with less influence include population growth ratio and shale gas production growth rate.

From all the indicators, scenario 4 shows the better results, and the closest trajectory to scenario 2. It has a moderate efficiency improvement rate and slow shale gas production growth rate. To adopt a more moderate production plan would also increase the possibility of introducing more efficient technology, especially on methane leaks and water usage.

5. Conclusions

The proposed model is simple. However, it considers the main issues involved in the production and the emission green house effect gases involved in the extraction and usage of Shale gas. As most models and scenarios, its objective is not to predict the future. Instead, it seeks to observe possible futures and its associated risks in order to identify intervention points to avoid unwanted consequences.

It is important to notice that the amount of emissions associated with the production and use of shale gas constitute a serious contribution to the amount of green house effect gases. Water consumption associated with the production is also an important issue. Therefore, it is far from being a sustainable source of energy.

As the obtained scenarios demonstrate, in order to improve the sustainability of energy consumption, to stabilize the population growth and to improve the efficiency is necessary. Diminishing population growth or improving the efficiency alone have positive results, however, both conditions together show the most effective results.

System dynamics methodology is a simple and powerful tool to simulate scenarios in which the quantitative variables are predominant. It is especially useful to simulate the values of indicators and indices.

A clear mechanism and an accurate selection of variables are fundamental to build an efficient model. Simplicity must not be rejected. A simple model does not mean that the model is not appropriate to describe the observed phenomenon. System dynamics or other numerical modeling tools are an important part of any technology assessment. It is important to not forget that the assessment is meant to find the possible scenarios, and it does not pretend to be a prediction. Scenarios are possible futures with the purpose to identify positive or negative outcomes of present decisions.

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