Reflections on Modeling Systems’ Resilience

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Paper Reference Number: 1112-111
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Abstract

Modeling sustainability of a system is a complex and challenging process. In addition, it might not lead to a factual answer in the end. Modeling systems’ resilience as opposed to systems’ sustainability is an approach to check the endurance of a system. There are different systemic approaches to model sustainability and also the resilience. This paper presents the domains where resilience and sustainability can be used interchangeably. Furthermore, a systemic approach to model systems’ resilience is assessed.

Key words: Systems’ Resilience, Sustainability, Complex Adaptive Systems, Systemic Modeling

1. Introduction

Current energy crisis and climate change catastrophe have emerged the use of sustainable systems such as solar systems. Implementation of such projects requires a sustainability analysis in order to ensure the durability and profitability of the projects. Current sustainability assessment models are restricted by the limitations of their boundaries. The emergence of dynamic and complex systems as a modeling method have already yielded favorable results in a variety of applications, such as modeling ants nests, local ecosystems, and large space-based projects where the interaction of the parts bears significant effect on the final outcome. It is suggested that the complex modeling methodology be applied to sustainable models in order to derive a more realistic outcome. In addition it is proposed to have a complex adaptive methodology for the effect consideration of the policies involved. The complex nature of sustainable systems requires a better conceptualization in order to able to model what needs to be modeled. This research tries to look at resilience of complex systems opposed to sustainability of system. It reviews the prospect of this approach through wide-ranging narrative extraction.

2.Sustainability

There are many different definitions for the term sustainability but what they all have in common is that they refer to an ongoing process and a systems' state. This means the sustainability of a system can be considered as a feature of the system. Here is a definition for the phrase:

"*The ability to maintain a balance in a process or a state in a system, whether ecological, technological or social is currently known as sustainability*" (Jahankhani et al 2009).

Brundtland report founded the grounds for primary generic sustainable models. This United Nations report introduced the term 'Sustainable Development' in different chapters and its elements were subsequently used in various sustainability representations. Later the Human Environment UN Conference in 1972 in Sweden elaborated on the work proposed in the Brundtland report. The latter report simply introduced Human and Environment as the only relation that need to be analyzed; although it has not introduced the detailed facts regarding the interactions (UNEP, 1972) The Brundtland report focuses on the notion of development. Furthermore, it defines the sustainability ability of the development by two major concepts; the needs and the ecological resources. The report emphasizes that the harmony between these two will assure a sustainable trend. This report also defines some other factors that affect the relation between needs and resources. In addition, political will is considered as a main factor for sustainability and development (Brundtland, 1987). Soon after, based on the intimations gotten from this report, the three dimensions of the three pillar sustainability model were brought in.

The vagueness of the Brundtland report was highlighted in the World Summit report which was held in 2002 (UN, 2002), The 2002 UN report, tries to redress the balance between the three themes of sustainability. During the last thirty four years different models were proposed from non UN independent academics, non academics, and industries.

Todorov & Marinova (2009) have classified all sustainability models into five main types: Pictorial Visualizations Models, Quantitative Models, Physical Models, Conceptual Models, and Standardizing models.

One proposed pictorial model/map for sustainable development built based on descriptive data is illustrated in figure 1:

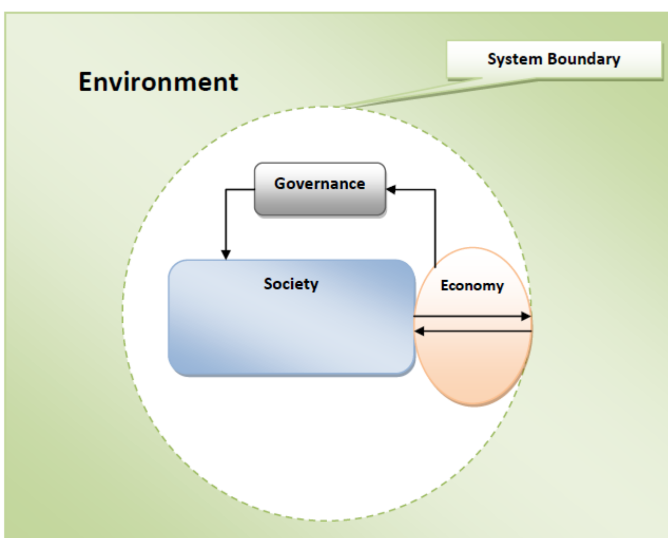

Fig 1: Proposed pictorial sustainability map

Where the map is regarded from the system perspective:

1. The system is part of the environment domain (European Commission, 2008).
2. The system contains interactions with the environment (European Commission, 2008)
3. The environment interacts with the society theme (Miller & Spoolman, 2009)
4. The requirements and resources of the society theme create the economy theme (Doran, 2007).
5. The environment gives feedback to the entire system through the economy domain (Gell-Mann et al 1990)
6. The governance module which was introduced in the Brundtland reports receives the feedback from the environment and society through the economy domain and tries to manage the society interactions (ENI, 2008).
7. Governance or politics is the main driver (European Commission, 2008).

3. Sustainability vs. Resilience

Resilience was initially introduced in the ecology science. The term was used as the ability of a system to pass and moderate a shock from outside.

Resilience as opposed to sustainability can be defined as:"*The capacity of a system to absorb disturbance and reorganize while undergoing change, so as to retain essentially the same function, structure, identity and feedbacks.*" (Hopkins, 2008). The schematic of this concept using the map illustrated earlier is presented below:

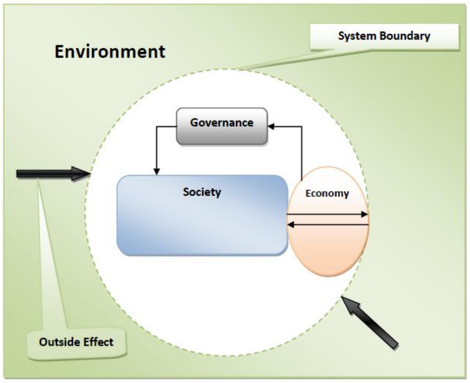

Fig 2: External impact to the system

4. Systemic Approaches

There are different systemic approaches to sustainability. According to (Todorov & Marinova, 2009) the system approaches are normally quantitative models. Some instances are outlined below:

Arbogast, Thornton, & Bradley (2010) established one of the latest Corporate Sustainability models. It describes the company sustainability using different variables and the indicators. In other words the sustainability for a company can be quantified using variable indices. The following variables are considered in the model:

1. Industry Group Percentile Energy Productivity
2. Industry Group Percentile Carbon Productivity
3. Industry Group Percentile Water Productivity
4. Industry Group Percentile Waste Productivity
5. Leadership Diversity

6. Percent Tax Paid
7. Sustainability Leadership

By taking a closer look at the variables, it is noticeable that they do not replicate the main elements which were described initially. The first four variables can be considered as the Environment Element, the fifth and the seventh are the Society or the human involvement in the model and the sixth variable is within the Economic domain. The mentioned variables are delineated as the independent variables and the corporate sustainability has been defined as the dependant variable where it depends on the mentioned variables. The regression equation used is as follows:

$$\hat{R} = b_0 + b_1 IGPEP + b_2 IGPCP + b_3 IGPWP + b_4 IGPWasP$$
$$+ b_5 LD + b_6 PTP + b_7 SL + b_8 T + b_9 SR$$

Equation 1: Arbogast regression equation for the corporate model

Where the '*b*'s are constant. Each '*b*' is the estimated coefficient of each variable. Now this is the question: How does the estimation take place? Arbogast and Bradley acknowledge that each variable is still open to research. The Model used is a cross-sectional quantitative research. The vagueness of the sustainability concept has been diminished using numerations.
An interesting simplification for sustainability has been used in a sustainability model used for rural water supply systems. This model categorizes the sustainability of water supply systems into three categories of Low Sustainability, Moderate Sustainability, and High Sustainability (Masduqi, Endah, Soedjono, & Hadi, n.d.). The model uses sustainable indicators, using nine variables. The quantitative methodology has used two main equations to enumerate the measurements:

Equation 2: First equation of Masduqi watersupply model

$$\begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0.948 & 0 \end{bmatrix} x \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix}_{assumption} + \begin{bmatrix} 0.679 & 0.153 & 0.210 & 0 \\ 0 & 0 & 0 & 0.103 \end{bmatrix} x \left(\begin{bmatrix} 0.723 & 0 & 0 & 0 \\ 0.863 & 0 & 0 & 0 \\ 0.370 & 0 & 0 & 0 \\ 0 & 0.774 & 0 & 0 \\ 0 & 0.658 & 0 & 0 \\ 0 & 0 & 0.942 & 0 \\ 0 & 0 & 0.722 & 0 \\ 0 & 0 & 0.653 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \backslash \left(\begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ X_4 \\ X_5 \\ X_6 \\ X_7 \\ X_8 \\ X_9 \end{bmatrix} - \begin{bmatrix} 0.022 \\ 0.046 \\ 0.012 \\ 0.027 \\ 0.056 \\ 0.012 \\ 0.010 \\ 0.069 \\ 0.037 \end{bmatrix} \right) \right) + \begin{bmatrix} 0.001 \\ 0.001 \end{bmatrix}$$

Equation 3: Second equation of Masduqi water supply model

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \\ Y_4 \\ Y_5 \\ Y_6 \end{bmatrix} = \begin{bmatrix} 0.993 & 0 \\ 0.582 & 0 \\ 0.360 & 0 \\ 0 & 0.625 \\ 0 & 0.407 \\ 0 & 0.659 \end{bmatrix} x \begin{bmatrix} \eta_1 \\ \eta_2 \end{bmatrix} + \begin{bmatrix} 0.001 \\ 0.022 \\ 0.011 \\ 0.054 \\ 0.058 \\ 0.015 \end{bmatrix}$$

The nine variables that the model has employed and used in the above equations are as follows:

1. Availability of water source
2. Selection of Technology
3. Investment Cost
4. Technical Operation
5. Institutional Management
6. Existence and Ability of Operator
7. Availability of spare parts
8. Operation Costs
9. Community Participation

The second equation uses observed variables which are known as indicators where the first equation is for latent variables. Two indices known as reliability index and sustainability index are defined via summation of different variables. The following path diagram (Fig. 3) is illustrating the influences of each variable on another. The path diagram can be replaced using influence diagrams:

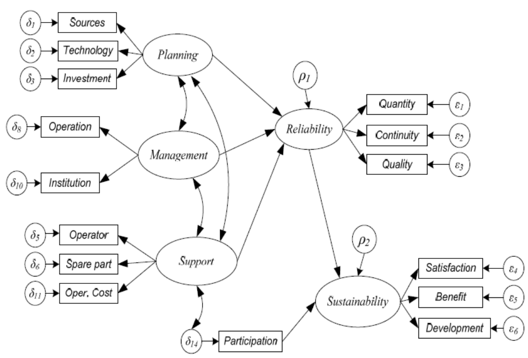

Fig 3: Masduqi Path Diagram

The model is a theoretical, quantitative model which uses cases studies and sustainability indicators. The variables stated, can be classified into the main popular three dimensions of sustainability: Economy, Environment, Economy.

One of the latest models that tries to provide a platform for engineering applications is called Sustainable Engineering Infrastructure or for short SEI (Okon, Ekpo, & Elhag, 2010). Basically the SEI model is a mathematical model which does not specify an application. It generates variables from the main three themes and some other overlapping areas.

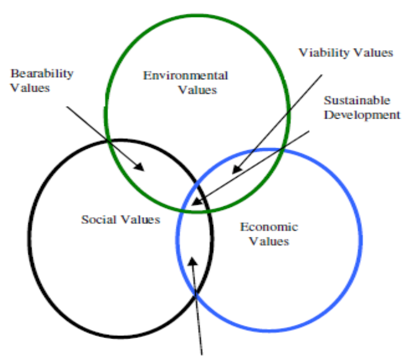

Figure 4: Sustainability Overlapping Thesmes

The illustration and the containing concepts provide the variables for the SEI model. The variables are then substituted into a mathematical equation. The final SEI model is represented as follows:

$$n(E_{cv}) \cup n(E_{nv}) \cup n(S_{ov}) = n(E_{cv}) + n(E_{nv}) + n(S_{ov}) - n(V_v) \quad - n(B_v) - n(E_{qv}) + n(S_{uv})$$

Where

S_{ov} – Social values.
E_{qv} – Equitability values.
E_{nv} – Environmental values.
E_{cv} – Economic values.
V_v – Viability values.
B_v – Bearability values and
S_{uv} – Sustainability values.

Equation 4:(Okon, Ekpo, & Elhag, 2010)

The set theory simply establishes the new sustainability model. The key thing to consider is to how select the involved variables. There are hundreds of Sustainability Models, and there are some common approaches in almost all of them, even though some are defined for a specific application and some like SEI can be considered as generic models.

Kwon (2007) has used the Complex Adaptive System tools and theories to model sustainability and to achieve what it called Green Growth. Fig. 5 shows the model where the elements are in the centre:

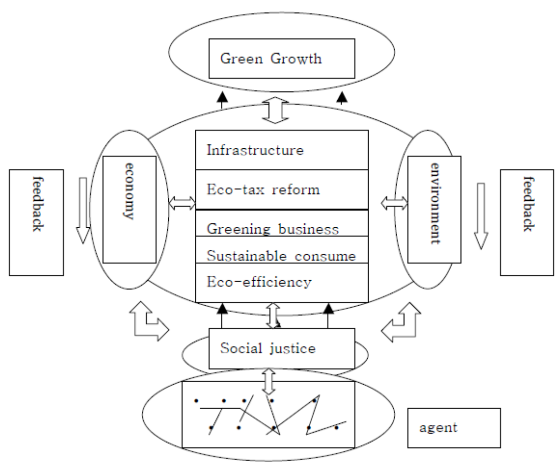

Fig 5: CAS representation of sustainability

The model has considered the main three themes, but the role of patents cannot be seen in this model. In addition, the Society domain is reflected as the agent of the CAS while the life styles which are still part of Society theme cannot be an agent.

The drawback for the above models is lack of practicality and extensiveness. Some are focused at one case study and some remain in theories. The common condition in all the above examples is that they follow the sustainability principles and none have used the resilience concept.

5. Complex Adaptive Systems to model Systems' Resilience

The pictorial model represented in figure 2. can be amended by substituting sub systems of the main systems. Each system can have its own systemic approach. The reason for this is the complexity of each from system of systems perspective. The hybrid systemic approach should have a more realistic result:

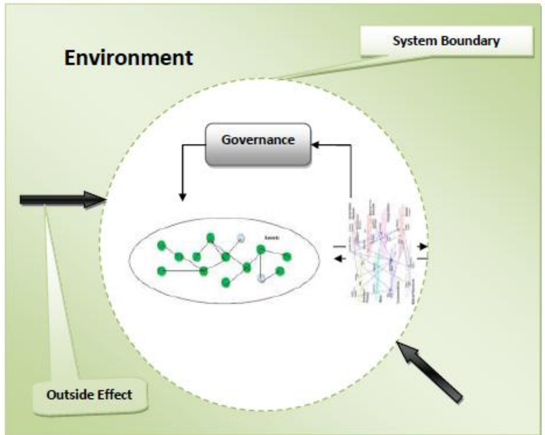

Fig. 6: Economy and Society themes are considered to be independent systems

The society theme may use a multi agent technique in order to evaluate the interactions and adjustments; which is really not the focus. It can be modeled using other approaches. The economy domain in our approach uses predictive approach or probabilistic systemic techniques which can be modeled using Bayesian updating. The tentative substitute picture is represented in fig 7:

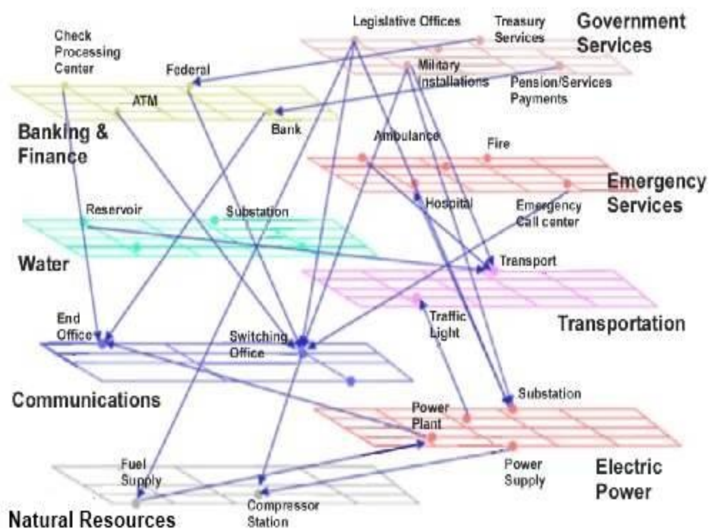

Fig. 7: Resources vs. consumption illustration in the economy sector (Stuart, 2010)

6. Conclusion

According to literature a system is sustainable where the links and the relations between the links can endure for the lifetime of the system. Alternatively, the concept of resilience as opposed to sustainability will assist the researchers to easier identify the endurance attribute of the system. If the resilience of the links between the components of a system is assessed based on the resilience factors set as criteria, the sustainability of the whole system will become certain. Inputting a system into a complex adaptive template, would provide a more

realistic illustration in order to eliminate the boundary paradox. As pragmatic nature of natural systems, are open systems and incorporating closed system models would affect the accuracy of the outcome, the CAS approach will provide a more accurate end result.
The assessment of the resilience nature of the links can be done by different approaches. One of the systemic modeling approaches would be the use of Bayesian networks. The proposal relies on identification of all components of a sample system, and the quantitative effect of one component on another. This can be represented by using degrees of memberships in Bayesian networks and Fuzzy logic. In addition Influence Diagrams or Decision Trees may be used to add a Decision Support System to the model.

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