Sustainable energy transition and climate change vulnerabilities: a resilience perspective

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Extended Abstract

This paper focuses on the energy transition in the context of climate change, the effects new and unexpected weather conditions will have on the energy systems and the actions policymakers might take to reduce these effects. The lessons learned in the case study of Guatemala are discussed in the light of how to create more resilience and sustainable energy systems. The results, even bound to exploratory, highlight the threats of climate change effects to renewable energy systems, namely in tropical countries. In this context, policies focused on enhancing resilience and flexibility are explored using simulation models as a proactive response to design and manage energy transition.

Energy transitions are "a shift in the nature or pattern of how energy is utilized within a system" (Araújo, 2014 p. 112). Recently the term energy transition has been mainly used to refer to the change in the primary energy source used to produce electricity. Transitions have happened in the past as industry moved from coal intense to oil and from oil to gas. Today, the paradigm shift in the energy systems is moving them towards renewable and more sustainable energy sources.

The transformation of energy systems through renewable energies is a structural change of the system that takes place over an extended period of time. The success of this transformation will depend, at least partially, on the extent to which this new more sustainable system would be able to retain its novel identity in spite of changes in the environment surrounding it. In other words, it will depend on how resilient new states of the system is.

Resilience is defined by Holling (1973, p. 17) as "the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist". If the desired state lacks resilience, the system might easily move to other undesired and even unexpected states compromising its functionality. Resources would be wasted if, in the long-term, the system does not remain as intended or the outcomes are not the expected ones.
Even risk management literature has explored some of this issues from a static perspective; little has been done to understand how the internal dynamic of the system can contribute or exacerbate the risk of failure. The endogenous dynamic of the system is necessary because the feedback loop mechanisms and the accumulated resources in the system might make the system more resilient by helping it to withstand disturbance or recover from them.

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Analyze the system from a resilience perspective helps policymakers to a) anticipate these undesired scenarios, b) identify vulnerabilities of the systems proposed, and finally, c) act proactively to reduce risk.

Assessment of resilience of energy systems, however, is not a straightforward process since these systems are complex. The behaviour of complex systems and their response to disturbances is driven by the feedback loop relationships between its main elements. Traditional analysis based on linear assumptions usually fail to account for this complexity and, therefore, the actions of individual actors will tend to be overlooked or misinterpreted.

To deal with this complexity, this paper uses a combination of system dynamics with performance management - dynamic performance management (Bianchi & Rivenbark, 2012)-. On the one hand, System dynamics (SD) provides tools for the analysis of complex systems and the effects of feedback loop relationships and delays through in the observable behaviour of complex systems through the use of computer simulation models (Richardson, 2011). Alternatively, performance management brings the framework to bridge the insights found using system dynamics into public management systems. DPM supports policymakers to assess middle and long-term impacts of their actions in the overall system by a) modelling organizational systems (in an SD model) and b) placing the measure of performance in a broader context of the system outcomes (Bianchi & Tomaselli 2013).

To achieve this, DPM operationalizes the analysis of policies on framework grouping three inter-connected views of the system performance (see Figure 2): i) an "objective" view; ii) an "instrumental" view; iii) a "subjective" view (Bianchi, 2012).

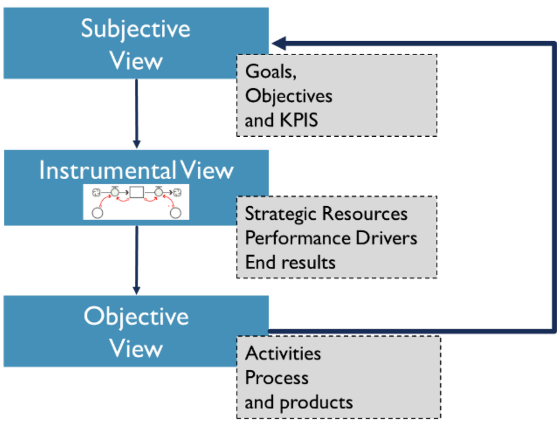

Figure 2: Three views of the DPM approach

The "objective" view opens the policymaking black-box and dissects the policy final outcomes into a sequence of products or services offered to internal and external clients. This view focuses on the actual activities and process that public bodies execute to implement the policy.

The "instrumental" view focuses on the dynamic structure and performance drivers producing the observed end-results. This view supports identification and understanding of a) the end-results, b) how strategic resources are built and depleted, c) relationships between strategic resources and performance, and d) the importance of these relationships over time.

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Finally, the "subjective" view links the previous two views in the context of the pursued objectives by aligning actions and process to strategic resources and drivers. This view comprehends the targets and precise ways to measure them.

In this paper, the five measures of resilience proposed by (Herrera & Kopainsky, 2015) to assess the resilience of the energy system studied. These measures, combine concepts from the resilience paradigms in a system dynamics context. Table 1 presents the proposed measures and their description.

Table 1: Measures of resilience in system dynamics models

Paradigm	Measure	Description	Mathematical definition
	Hardness	The ability of the system to withstand a disturbance σ without presenting change in the performance of the outcome function F(x)	$\sigma_M = \delta_M \times (t_d - t_e)$ (2)
Engineering resilience	Recover Rapidity	Average rapidity of the system's recover from a disturbance σ (Attoh-Okine, Cooper, & Mensah, 2009)	$\bar{R} = \frac{D-C}{t_f - t_d}$ (3)
	Robustness	The ability of the system to withstand big disturbances σ without significant loss of performance (Attoh-Okine et al., 2009)	$\bar{\rho} = \frac{\sigma}{D-C}$ (4)
Ecological resilience	Elasticity	The ability of the system to withstand a disturbance σ without changing to a different steady state	$\sigma_L = \delta_L \times (t_d - t_e)$ (5)
	Index of Resilience	The probability of keeping the current steady state or regime.	$P(S_0 \parallel \sigma)$ (6)

This paper use the energy transition in Guatemala as study case. This case yields both practical and theoretical insights about energy systems and transition policies. These insights are not applicable only to the particular case of Guatemala but invite to a careful analysis of the energy systems based on renewable resources and the policies need for its successful implementation.

From the practical perspective, suggest potential alternatives to enhance the resilience of hydroelectric based energy systems in the context of climate change. It seems necessary to create financial mechanisms that help private and public investors to withstand the inconsistencies result of climate change. Since renewable energy source required of high investment while having low operating costs, the volume of energy produced and the consistency of it are key ingredients for its financial success. The foregoing is not only applicable to hydroelectric plants but also for windmills and solar panels. Energy transition strategies should acknowledge this variability and implement mechanisms to support sustainable growth of the renewable sector in spite of a more unpredictable weather.

From a theoretical perspective, it shows the vulnerability of strategies designed based on past performance of simple correlations. The analysis of the problems from a resilience perspective can support policy makers to uncover potential vulnerabilities and to identify means to enhance the sturdiness of strategies for energy transition. Conceptualize risks from a resilience perspective supports the identification of leverage points and allows to make objective comparisons between potential policies. Moreover, from a public policy perspective, a resilience analysis using DPM offers a tool for economic appraisal and performance measure of projects and policies.

It is important to highlight that energy systems are complex and the model presented in this paper, even insightful, is highly aggregated. For instance, the results presented in this paper will benefit from further research including the dynamic of the energy demand since it is currently considered as an exogenous variable. It is also important to assess alternatives to hydroelectric generation, for instance, options for windmills and more geothermal powered plants.

Energy transition is necessary to evolve from fossil fuel dependence to a more sustainable energy production. However, energy transition strategies might fail to anticipate financial and implementation challenges if it is planned and designed with a static perspective. Underestimate the increase in weather variability might result on renewable energy systems that are unsustainable from an economic perspective, discouraging and slowing the transition.

The results and analysis presented in this study case, exemplify how climate change effect can compromise the policies for energy transition and reduce their effectiveness. Same results suggest the importance of creating sustainable financial mechanisms to protect public and private investors of climate change effects.

Moreover, the analysis highlights the importance of assess risks timely and act proactively in the energy industry by using a resilience perspective and dynamic performance management. Better understanding of the system vulnerabilities and dynamic yields opportunities to make public expenditure more efficient and effective by preventing policies to fail in the long term.

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