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System dynamics approaches to energy policy modelling and simulation

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Abstract

Energy systems are complex dynamic systems that are often associated with uncertain system behavior. System behavior is influenced by several dynamic uncertainties, nonlinear relationships between system variables, time lags, and interactive feedback loops that are inherent in the energy system. In turn, these complexities are a result of the underlying structures of energy systems. Under this climate, it is essential to develop systems analysis approaches that can be used for development and evaluation of energy system policies, both at tactical and strategic levels. The purpose of this research is to present a taxonomic analysis of system dynamics approaches to energy policy modelling and simulation. First, we present an outline of dynamic complexities prevalent in energy systems. Second, we make a taxonomic analysis of energy policy formulation problems, learning from the literature. Third, we provide a causal loop analysis of the generic structures of the identified energy formulation problems. The archetypes presented form a valuable platform for system dynamics simulation of energy policy modelling and simulation.

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Keywords: Energy policy; energy mangement; simulation modelling;energy policy modelling; system dynamics

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1. Introduction

Energy systems continue to grow in size and complexity [1] [2]. Several issues and challenges continue to emerge in the energy industry in developed and developing economies. For instance, the energy industry has experienced widespread deregulation in electricity markets and electricity industry, which directly affects energy policy formulation and implementation. Moreover, technological changes and advances have impacted energy policy development and management. Global environmental concerns and issues, coupled with trends in global climate change, have been a major cause for concern in energy industry [3]. As a result, energy policy formulation often involves several stakeholders whose inputs and expectations are to be taken into consideration, if the policies are to be a success. This has exacerbated the dynamic complexities of energy systems. Such dynamic complexities include uncertainties, nonlinear causal relationships among system variables, interacting feedback loops, and time delays [4] [5] [6] [7] [8] [9]. Faced with these challenges and other pertinent issues in the energy industry, energy policy makers have to devise efficient and effective dynamic simulation methodologies which can handle complex energy systems.

Due to the existence of multiple energy demand and supply related factors, the dynamics of energy systems has become a serious challenge to the policy makers. Influenced by emerging changes in the energy market, consideration of uncertain complex dynamic aspects in the policy formulation process is imperative. In retrospect, these complex challenges and issues should be addressed in energy policy formulation and evaluation. To that effect, the purpose of this paper is to present system dynamics approaches to energy policy modelling and simulation. In light of this, this research follows through the following objectives:

1. To identify the dynamic complexities and challenges that are often associated with complex dynamic energy systems;
2. To develop a taxonomic analysis of energy policy formulation problems so as to visualize their generic structures; and,
3. To make a causal loop analysis of the identified energy policy formulation problems based on their generic structures.

The suggested generic causal loop structures provide a platform for system dynamics approaches to energy policy modelling and simulation. The causal loop structures can be useful to analysts and decision makers in the field of energy policy formulation.

The rest of the paper is structured as follows: The next section presents an outline of dynamic complexities prevalent in energy systems. Section 3 presents a taxonomic analysis of energy policy formulation problems, learning from the literature. Section 4 provides a causal loop analysis of the generic structures of energy formulation problems.

2. System dynamics archetypes for copying with dynamic complexities

According to Wolstenholme [7] [9], system dynamics archetypes are generic structures of systems that describe the dynamic system using causality cycles, positive (or reinforcing) and negative (or balancing) feedback loops. In other words, system dynamics archetypes are a useful approach for evaluation of the dynamics of possible scenarios of complex systems [8]. In this respect, system archetypes can assist policy makers to effectively visualize the entire energy system in order to predict unexpected system behavior.

Understanding systems variables and their interactions is very important when analyzing the behavior of complex systems, such as energy systems. In practice, essential system variables are always found in archetypes [7] [9]. Almost always, there exists a generic archetype for each generic problem archetype. Therefore, system archetypes are a useful platform modelling complex dynamic systems.