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Applying Systems Thinking to Analyze Wind Energy Sustainability

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Abstract

Wind energy, along with other renewable energy sources, has become an alternative to traditional energy sources to meet the growing energy demand. Wind energy is considered to be one of the cleanest sources of energy. Wind energy sustainability focuses on a balance between economic, social and environmental objectives. However, wind energy faces various challenges associated to sustainability. This paper presents a way to analyze wind energy sustainability using a systems thinking approach.

Keywords: wind energy sustainability; systems thinking; causal model; system dynamics

1. Introduction

Sustainability is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"[1]. The United Nations[2] recognizes major components of sustainability to be social development, economic development and environmental protection. These are described as "three interdependent and mutually reinforcing pillars"[2].

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Renewable energy sources are considered a cleaner way to produce energy. Renewable energy sources emit a reduced amount of greenhouse gases compared to traditional sources of energy. However, there are negative impacts associated to their use that have to be considered to ensure a more sustainable energy system as a whole.

Wind energy, along with other renewable energy sources, has become an alternative to traditional energy sources to meet energy demand. Wind energy is one of the fastest growing renewable energy sources worldwide[3]. However, wind energy also faces multiple challenges related to the three key sustainability pillars (social, economic, and environmental). Wind energy competes with traditional electricity generation for market share. Wind energy projects may compete with other uses of the land. Negative environmental impacts from a wind energy project can increase local community opposition. To achieve overall energy system sustainability, it is crucial to achieve wind energy sustainability.

Systems engineering deals with sustainability concerns from system concept through disposal. Systems engineering addresses complex systems. Systems engineering provides methods, including systems thinking methods, that facilitate the understanding of complex systems. An objective of systems engineering is to better understand the structure of a system and its behavior. Systems engineering focuses on understanding key elements of the system and the interaction between elements within the system and its environment. The energy system can be considered a complex system of systems. Systems engineering can help to address the sustainability challenges related to energy systems. Snyder[4] highlights the need to apply systems engineering to transition to sustainable energy systems since a systems engineering process could help in the planning, development and implementation of new technologies as well as in dealing with the heterogeneous set of stakeholders in today's energy systems.

A systems thinking approach is used to analyze wind energy sustainability. A causal model was developed to illustrate factors and factor relationships related to wind energy sustainability. The purpose of the causal model is to serve as an aid for decision makers to analyze the impacts of their decisions.

Section 2 of the paper provides a brief overview of energy system sustainability. Section 3 presents an overview of wind energy sustainability and why it is important. Section 4 provides background information related to systems thinking. Causal model background information is presented in section 5. The wind energy causal model is presented in section 6. Causal model factor definitions and factor relationships are also included in this section. Section 7 discusses the model validation process. Section 8 provides a summary of the paper and future work.

2. Energy system sustainability

The availability of energy is critical to ensure economic and societal development[5, 6]. The energy system can be considered as a system of systems. The energy system of systems is composed of multiple systems, each capable of performing their functions in isolation, but interconnected for a common goal, to provide energy products to end users. The energy system is dynamic and continuously evolving. Multiple subsystem configurations coexist while transitioning to a more sustainable energy system. Different sources of energy are required to work in interconnected systems. A heterogeneous set of stakeholders with different objectives, and a continuous integration of additional elements to the energy system of systems contribute to the complexity of the energy system.

Leveraging the WCED[1] sustainability definition, energy sustainability can be defined as an energy system that meets the needs of the present without compromising the ability of future generations to meet their own needs. A balance among economic, social and environmental pillars is required for a sustainable energy system.

The energy system faces various challenges. According to the International Energy Agency [7], the energy sector is responsible for the largest amount of greenhouse gas emissions in the world. Other concerns related to energy are environmental damage, potential adverse health effects in communities where energy facilities are located, and depletion of traditional energy resources. Some of these challenges also apply to wind energy systems. In this paper the authors focus on one system of the system of systems, wind energy.

3. Wind energy sustainability

Wind power generation has 125 years of history[8]. The behavior of the development and use of wind energy has been associated with fluctuation in oil prices and supply[9]. Wind energy is considered to be one of the cleanest sources of energy. However, wind energy faces various challenges. Due to the nature of wind, wind energy