Sustainable Energy System Planning in Developing Countries: A Decision Support System Considering Variations Over Time

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Abstract

Planning energy systems is subject to changes in components' health and installation costs, fossil fuel prices, and load demand. Especially in developing countries, electrical loads are reported to increase drastically after electrification. Improper sizing of the energy system's components can lead to reduced environmental sustainability, decreased reliability, and long-term project failures. As no tools for energy system planning exist that aim at developing countries and sufficiently account for temporal variations, we modify the software NESSI4D in a design science cycle to provide the comprehensive decision support system NESSI4D$^+$. We conduct an applicability check with a representative rural village in mountainous Nepal that validates NESSI4D$^+$'s relevance and shows the importance of considering temporal variations for economically, ecologically, and socially long-term sustainable energy projects.

1. Introduction

Decentralized energy systems have proven economically and environmentally successful solutions to electrify areas in developing countries [1]. However, the planning process of energy systems is subject to considerable uncertainty, making the selection and sizing of appropriate energy technologies challenging. Small oversights can lead to unreliable electric supply, unnecessary high costs [2], underestimated environmental impacts through unexpected fossil fuel consumption, and, ultimately, failing energy systems [3]. Most pressing issues are time varying factors, such as demand changes, price volatilities and component degradation [3]. The former are particularly prevalent in developing countries within areas with no prior access to electricity. Díaz et al. [4], for example, report a doubling of energy demand in several off-grid rural communities in Argentina over an eight-year period. With the United Nations' commitment to support the provision of clean, reliable, and affordable energy under the seventh Sustainable Development Goals (SDGs), extensive financing and funded projects have been launched. These are steadily improving supply chains to developing countries and promoting competition within these, steadily facilitating access to renewable energy technologies (RETs) through price reductions and local availability [5]. At the same time, fossil fuel prices are expected to rise in the future due to decreasing availability, increasing awareness of their environmental impact, and overall rising energy consumption [6]. Components' degradation over time and use leads to efficiency losses and unavoidable reinvestment, affecting the performance and cost of the power system and creating project risks [3]. Consideration of these circumstances is particularly relevant in developing countries, where second-hand products are often used and proper maintenance is not always guaranteed.

It is therefore crucial that stakeholders are enabled to account for these temporal variations in their planning process. Information systems (IS) research is uniquely able to empower decision-makers through decision support systems (DSS) [8]. However, we found no tool in or outside the IS community aimed specifically at developing countries offering the needed functionalities. The focus on developing countries is essential as existing energy system models are often biased toward industrialized countries [9]. Motivated by this gap and the call for more solution-oriented Green IS research [10], we explore the following research question:

> *How can a DSS be developed to assist stakeholders in designing sustainable and long-term successful energy systems by considering variations over time?*

As a basis, we use the DSS NESSI4D which is based on NESSI by Kraschewski et al. [11] and was specifically designed for stakeholders and circumstances in developing countries. Leaning on the design science research (DSR) methodology, we modify NESSI4D to