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Sustainable Energy System Planning in Developing Countries: Decision Support Considering Socio-Cultural Dimensions

MASTERARBEIT

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1 Introduction

The asymmetry of the world countries’ development is growing because types of inequalities arise. This development increases the gap in the living standard for the population [1]. As a result, the energy supply has also been affected. While in industrialized countries, for example, there are discussions about whether wind turbines will be accepted because of their heights, citizens in developing countries face completely different challenges. Nowadays, more than 700 million people still live without access to electricity, primarily concentrated in Sub-Saharan Africa where three-quarters of the population lack access [2]. This is indicating that the world is not currently on track to reach the goal of full access to energy for all by 2030 set by the United Nations (UN) [3]. This deficit needs to be emphasized because energy supply is a key issue at the heart of modern society [4] and it is necessary to enhance human life [5]. Making a rapid transition to a clean energy future for all will have enormous impacts on the quality of people’s daily lives as well as on the survival of future generations [2]. Because of the abundance of resources in most developing countries, widespread expansion renewable energy generation is possible. It is the lack of exploitation of the potential that contributes to the problem. In Madagascar, for example, less than 5% of renewable resources are exploited [6].

To transition over to sustainable energy systems planning and decision support are highly needed to accomplish changes. Taking note of the following, sustainable development of energy systems requires consideration of all three sustainability dimensions: environmental, economic, and social [7]. Since the late 1980s, much of the debate on sustainability has been dominated by environmental and economic perspectives. However, the last decade has seen an increasing interest in the social aspects of sustainability. While, to some extent, a general consensus has been reached regarding the definitions of ecological and economic sustainability, the definition of social sustainability is still in the making [8]. There is a lack of theoretical and empirical studies regarding social sustainability. Efforts to achieve sustainability will be undermined without socially oriented practices [9]. Therefore, there is a need for conceptual frameworks and theoretical constructs in order to further develop the understanding of social sustainability. In the context of energy system planning, there are various tested approaches including assessing social aspects. However, measuring the social sustainability of energy systems is complicated due to the fact that there is no universally accepted definition of social sustainability [10]. Hence, more work is needed to integrate this dimension with quantitative modelling [11].

Aiming to fill these gaps and incorporate social sustainability into decision support systems (DSS) for developing countries' energy systems, the following research questions (RQ) are explored:

RQ1: How can energy systems be assessed for their social sustainability?

RQ2: To which extent can the social dimension of sustainability be integrated into a DSS?

To achieve this paper’s goal and to address the RQs, the author concepts a methodology for the assessment of energy systems with a DSS. The main part of this methodology is a framework that includes criteria and indicators for the assessment of social sustainability. The initial framework is based on extensive literature research and analyses of recent studies. Expert interviews were conducted to verify the framework. Based on this, an implementation of social indicators in the extended version of the Nano Energy System Simulator for Development (NESSI4D 0.2) is attempted. To evaluate the ability of the implementation and to allow recommendations about energy systems planning, neighbourhoods in Madagascar are analysed regarding a Social Sustainability Score (SSS) of different energy systems.

For this purpose, this paper is structured as follows. Section 2 provides a theoretical foundation with a focus on getting knowledge on social sustainability. Subsequently, the designed methodology for modelling energy systems is presented in Section 3 as well as analyses of established DSS and recent studies concerning energy systems. An initial framework for assessment of social sustainability is created which is evaluated and discussed within expert interviews. The implementation of the verified framework in NESSI4D is shown in Section 4 with simulations of different energy systems for neighbourhoods in Madagascar. Reviewing the scenario comparison, a discussion with recommendations is given. Section 5 provides limitations of the framework, implementation in NESSI4D 0.2, and the analyses. Possibilities for future research are presented. Lastly, the paper is concluded in Section 6.

6 Conclusion

Rising inequalities in the standard of living and the increasing importance of electricity for the quality of life fuel debates about the social sustainability of energy systems. Therefore, this work aimed to elaborate the theoretical foundations of sustainability and design a framework to assess and implement the social dimension in a DSS with a focus on energy system planning in developing countries. In the following, the two research questions are answered along with a reflection on the procedure and results of this work.

RQ1: How can energy systems be assessed for their social sustainability?

A methodology is designed in Section 3 which serves as a guideline to answer the two research questions. In essence, it provides a framework for assessing social sustainability. The initial framework is primarily founded on literature research and the results of recent studies. Based on this, criteria and indicators are selected for describing the social dimension. A criterion is the basis for decision-making that captures a single issue or area of concern while an indicator measures the performance of each technology for the criteria in question. The social criteria are assigned to the two categories of physical well-being as well as quality of life and equality. The first category consists of the criterion ‘health and safety’ which describes the morbidity and mortality rate of energy technologies. Quality of life and equality are influenced by four criteria. Firstly, ‘employment’ indicates the number of jobs created by manufacturing, installation, operation, and maintenance of the energy system. Secondly, ‘security of supply’ measures the reliability of energy provision and availability of the system. Thirdly, the land use, noise exposure as well as pollution and GHG emissions of the system are considered in the ‘effects on the quality of landscape and environment’. Lastly, social acceptability and self-sufficiency are described by ‘society and culture’.

These criteria and indicators are verified by expert interviews. The experts state that social acceptability, noise exposure, and indicators for health and safety are less important in developing countries. These indicators are more prevalent in developed countries. Further, scoring and weighting options are set up to calculate the criteria values and a Social Sustainability Score. This score indicates the social performance of the energy system with 0 being worse and 1 being best.

RQ2: To which extent can the social dimension of sustainability be integrated into a DSS?

A missing uniform definition, the complexity of assessment, and insufficient data hamper progress in the implementation of the social dimension into decision support tools. However, the designed methodology in this work enables integration. The initial framework described above needs discussion and adjustments by expert interviews. Therefore, it is particularly important to talk to experts who have experience in developing countries in order to get an accurate insight into real conditions. The result of this step is a verified framework with a range of criteria, indicators and sub-indicators describing the social dimension. This framework is implemented in a DSS named NESSI4D 0.2. However, the full extent cannot be integrated. On the one hand, some indicators are merged or omitted because of invalid and missing data. On the other hand, NESSI4D 0.2 can assess the social sustainability of island power grid solutions supplied by renewable energy technologies and diesel generators with optional battery storage. The options of accessing electricity by a central power grid and the thermal infrastructure are omitted.

To evaluate the applicability of the tool, case studies for two representative neighbourhoods in Ambovombe in Madagascar are conducted. Various energy systems are analysed in their technical, economic, ecological, and social performance. The results show that an island power grid system with a locally produced wind turbine and PV module combined with battery storage has the highest SSS and so the best social performance. This finding is in line with the technical, ecological, and economic results delivered by the system. Solutions with a diesel generator show high costs and GHG emissions and additionally below-average to moderate social performance. However, reliable security of supply can be guaranteed with this technology. Island power grids supplied by a PV module with battery storage are suitable energy systems for neighbourhoods with relatively low annual energy consumption. This system indicates low costs and therefore, it is especially preferred for low-income households. In addition, the second highest SSS can be achieved and the systems performs well in ecological regards.

It is important to note that weighing the different dimensions of sustainability is necessary for considering energy system planning. Almost no system can show the best performance in all dimensions so trade-offs need to be made. Therefore, stakeholders need to define their preferences. The weighting options for the social criteria enable the integration of stakeholders' preferences and thus improve decision support.

The results of these analyses are discussed in detail and recommendations are formulated for the energy system planning in developing countries considering social sustainability as well as for the implementation of this dimension into a DSS.

In conclusion, the tool can provide decision support considering the socio-cultural dimension of sustainability for neighbourhoods’ energy system planning in developing countries. Therefore, as NESSI4D 0.2 has proven its value for energy system planning in developing countries and the topic’s relevance, its further development is highly recommended. As headlines worldwide focus on soaring energy prices in the developed world, the true global energy crisis is in developing countries where vast populations still cannot access basic energy services. Currently, Madagascar also faces a great drought. Comparable problems increase in the future due to climate change. Therefore, achieving SDG7 is becoming more and more important to achieve far-reaching changes in people's physical well-being and quality of life to build a socially sustainable world.