Leibniz Universität Hannover
Wirtschaftswissenschaftliche Fakultät
Institut für Wirtschaftsinformatik

Optimization of Decentral Renewable Energy Systems for Developing Countries

Masterarbeit

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vorgelegt von

Maria Christina Gudrun Hart
[redacted]

Prüfer:
Prof. Dr. Michael H. Breitner

Betreuer:
Prof. Dr. Michael H. Breitner
M. Sc. Sarah Eckhoff

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1 Introduction

In the past decades, rising prosperity and population growth have led globally to increasing energy consumption of virtually all energy sources [1]–[3]. Over 70 % of the worldwide demand for electricity is sourced from fossil energy, such as coal, natural gas, and crude oil [1], [3]. However, these reserves are finite and depleting, resulting in imminent energy shortages around the globe [2], [4]. Moreover, fossil fuels generate emissions that reinforce global warming and have harmful impacts on people's well-being [1], [5]. In fact, two-thirds of the global greenhouse gas emissions are considered to stem from the energy sector [6]. One way to address these problems is to decrease the individual's energy consumption by increasing the public's awareness and supporting energy-efficient technologies [3]. Another solution is the shift to alternative energy sources such as renewable energy systems [3]. The latter has additional beneficial effects, like dependency reductions on fuel imports and related costs. Renewable-powered mini- and microgrids or distributed systems may further allow electrification in remote areas, where grid extensions are economically and technically infeasible [7]. However, especially in developing countries, relatively high initial costs and uncertainty regarding an appropriate energy composition prevent individual households, village heads, and governments from adopting renewable energy components [3]. The stakeholders are challenged by the need for knowledge about the energy components' technical specifications, conditions at the site, and consumer-specific energy demands [3], [8]. Programs have been incorporated globally, but these often fail to include the users' needs and views [9]. Social and cultural issues of target communities result in low acceptance leading to the failure of long-term success [9]. Therefore, this work argues that stakeholders at the site must be assisted directly in their decision process for an economical, social, and ecologic sustainable energy composition. Thus, the following question is evaluated:

> *How can stakeholders in developing economies be aided to make viable decisions about optimal energy systems for buildings and neighborhoods considering location-specific circumstances?*

For this purpose, a simple decision-support tool tuned for the needs of people living in developing countries is developed. The aim is to make reasonable inferences about a sensible energy system at the evaluated site with the software's results. The program is based on the energy system simulation software NESSI by Vinke et al. [10] and Eckhoff [11], which considers assumptions applicable to developed economies and focuses on the energy-generating components of the thermal infrastructure. Its extension includes the implementation of additional electric energy components such as the wind turbine, diesel generator, island power grid, dump load, and scooters on the one hand and the adjustment of pre-defined assumptions on the other hand. The drawback of simulation tools is often that they require advanced abilities and knowledge of the user and comprehensive input data [12]. Therefore, this work provides a detailed explanation of the components' functioning and gives guidance on obtaining the required input data. Further, the software is designed for a high degree of usability. To evaluate the software's ability to allow fundamental inferences about an energy system, buildings, and neighborhoods in three representative locations are analyzed. A satisfactory level of detail of the input data is accomplished by synthesizing the respective load profiles with statistical analyses of survey data and using a modified version of the software RAMP. To account for location-specific conditions, the local, national, and international energy situation and its challenges are evaluated and considered in the analyses.

The following work is structured as follows: Section 2 introduces the basics of energy systems and their electrical energy components. Section 3 presents the simulation software NESSI and the modifications in its extended version. Subsequently, in Section 4, the software is tested. In this regard, the world's overall energy situation, its challenges, and international commitments are presented to provide necessary background information. Embedded in this, three representative locations in developing countries are analyzed and interpreted, considering national and international goals. In Section 5, the analyses' results, limitations, and possibilities for further research are presented and discussed in light of the research question. The work concludes with Section 6.

6 Conclusions

Rising energy demand, depleting fossil fuels, and aiming for an ecologically more sustainable energy system have motivated stakeholders to rethink energy infrastructures. However, implementing an energy system that supplies reliable, feasible, and low-emission electricity is a demanding task. Therefore, this work evaluates how to aid decision-makers in the developing world and evaluates the usability of simple software-supported simulations for buildings and neighborhoods. For this purpose, the nano energy simulation software NESSI is tuned for the peoples' needs in developing economies and subsequently applied in three representative locations. It is found this tools is an appropriate method to support fundamental inferences about an optimal energy composition considering the circumstances and individual preferences of stakeholders in developing economies.

The modification of the software includes an expansion of the existing database and the alteration of assumptions. Moreover, the electrical infrastructure is extended. On the one hand energy producing components like a wind turbine, a diesel generator, a PV system and an island power grid are included. On the other hand, scooters and location-specific data for the villages Ambovombe in Madagascar, Hue in Vietnam, and Klang in Thailand are added. The latter includes the statistical evaluation of reports from the World Bank and survey data from the TVSEP with STATA to develop household and industry profiles. These are used as inputs to generate synthetic load profiles with a modified version of the software RAMP.

The extended software named NESSI 2.0 is then applied to three representative villages, whose economies and energy targets differ significantly:

Madagascar is characterized as an underdeveloped country concerning its energy situation, with only 15 % of the population connected to electricity. Hence, for Ambovombe, a feasible energy system is targeted that generates energy for essential loads. The PV system presents the most feasible solution for the buildings and the neighborhood simulation. Besides the costs, its sizing flexibility plays a vital role. To ensure a reliable supply, additional battery storage is suggested. It is further found that considerable cost reductions are obtained by allowing uncovered load. As short-term solutions for entities with significant monetary barriers, small variances could be accepted to pave the way for electrification.

The Vietnamese energy production increasingly relies on coal, which goes against the government's goal to reduce greenhouse gas emissions. Therefore, the effects of low-emission energy solutions with changing component costs are prioritized for Hue. The results depict that the goal of feasibility and emission reductions contradict in the most cases due to the costs of the renewable components and battery storage, on the one hand, and low costs for electrical procurement from the central power grid, on the other hand. This disadvantageous relation is expected to change in the future towards lower costs for renewable energy producers and significant price increases for central power grid procurement. A sensitivity analysis, including predicted price trends for the years 2030 and 2050, suggests a cost- and emission-reducing solution that favors renewable energy producers.

The stakeholders in Thailand are concerned about the dependency on imports. Therefore, in Klang, an autonomous system's price is evaluated to relieve the central power grid's suppliers and reduce dependencies on fossil energy imported from other countries. Hereof, the influence of increased electricity demand is analyzed, which is represented by a switch from conventional to electric scooters. The results suggest the need for more substantial price incentives for the people from policy-makers. With the given costs, electric supply from the power grid is economically almost always preferred. However, the switch to renewable components only decreases dependencies on other states if they can either be produced and maintained in the country, or several importers are available.

The following discussion points out that it is possible to make fundamental decisions regarding a sensible energy mix for different situations based on the calculation of the extended simulation software NESSI 2.0. Of course, this approach is subject to certain limitations, which require an adaptation of local resources and conditions. Further shortcomings include the software's simplified design, the need for more in-depth analyses, and the omission of valuable factors such as detailed financial settings. Future research may implement additional components, business models, and credit structures. Further, the merge of the software RAMP and NESSI 2.0, as well as optimization algorithms, are suggested. In the context of the ultimate goal to directly support decision-makers in developing countries, NESSI 2.0's migration to other programming languages is also strongly advised.

In conclusion, the tool is able to support households and village heads in their decision-making process for a viable energy system composition. On a bigger scale, policy-makers are aided to formulate site- and target-specific recommendations that conform to the national and international goals of feasibility, reliability, and emission-reductions. Therefore, as NESSI 2.0 has proven valuable for the pre-design of energy systems in developing countries, its further development is recommended.