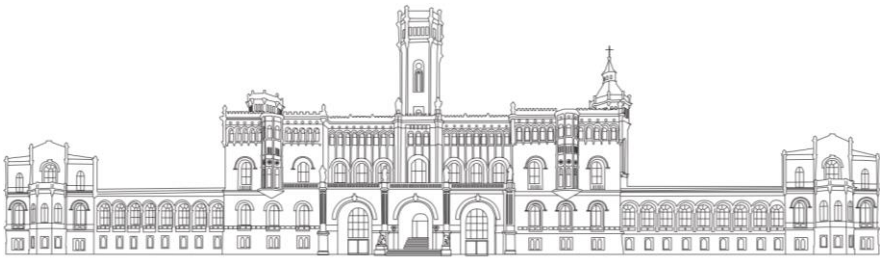

LEIBNIZ UNIVERSITÄT HANNOVER
WIRTSCHAFTSWISSENSCHAFTLICHE FAKULTÄT
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Decentralized Renewable Energy Systems in Developing Countries: Development of a Decision Support System

Masterarbeit

zur Erlangung des akademischen Grades „Master of Science (M. Sc.)“ im Studiengang Wirtschaftsingenieur der Fakultät für Elektrotechnik und Informatik, Fakultät für Maschinenbau und der Wirtschaftswissenschaftlichen Fakultät der Leibniz Universität Hannover

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1 Introduction

The biggest threat to the human species is anthropogenic (Ripple et al., 2017). The science of global risk analyses and emerging risks set out to find solutions on how to manage them. Potential global risks include human-made risks, natural disasters, and extra-terrestrial risks. While the latter two risks are not recognizable in near future, the environmental pollution and pollutants originating in human activity have become one of the foremost risks to have ever emerged.

Main concern regarding this topic is the rapidly increasing growth of energy demand and the unsustainable way this demand is covered. In 2019 above 80% of the global energy consumption needs were filled by fossil energy sources. As these conventional energy sources are not sustainable over time, they have been predicted to be depleted in the future. Research shows crude oil reserves will last an estimated 50 years at the current production rate (bp, 2020), which will result in a possible energy crisis, which demands the replacement of conventional sources with sustainable sources.

Using conventional energy sources has been widely known to cause another great problem, i.e. combustion releases great amounts of greenhouse gas emission. Particularly carbon dioxide (CO_2), carbon monoxide (CO), and Chlorfluorocarbon (CFC) along with other anthropogenic emissions contribute largely to the increase of global temperatures (Montzka et al., 2011). Global warming accelerates the melting of polar ice, depletion of ozone shields, and results in rising sea levels. It promotes extreme weather events like heavy rainfall and droughts (EPA). The quick increase of temperature changes animals' habitats faster than they can adapt to, eradicating a lot of species (Ceballos et al., 2015). Developing countries are among the most affected, as people there depend heavily on an intact natural environment and a balanced ecosystem (CanadaGov, 2021). Since climate change is a global issue and has been existed for decades, a variety of pacts have been signed over the years to counter the issue.

The solution to this steadily-growing problem can be provided by a global shift from conventional to sustainable energy sources like wind, solar, geothermal, and biomass energy, which in 2020 only contributes a little over 15% to the global energy consumption. The Stockholm Action Plan of 1972 was the first time any proposal from UN highlighted the connection between energy and environmental power and marked the beginning of international environmental politics. Since the Stockholm Action Plan, numerous international consultations and reports have emphasized the importance of introducing renewable energy systems. (Luomi, M., 2020). The International Conference on Renewable Energy (ICREN) brought the Johannesburg Action Plan in 2002, which embraced that the admittance to sustainable energy resources was instrumental in accomplishing the Millennium Development Goals (MDGs), set by the UN to address the issues of the world's under-developed countries by 2015. UN-Energy

was established in 2004 with the aim of ensuring follow-up of various decisions that were made in Johannesburg. (Luomi, M., 2020). In 2015 an UN-Agenda was released for sustainable Development by 2030 and its 17 Sustainable Development Goals (SDGs), signed by 193 countries. According to the SDG, the share of renewable energy in global energy integration must be significantly increased, and the use of renewable energy infrastructure and energy technology will be promoted till 2030. Developing countries often don't have the resources and capabilities to deal with the challenges of climate change and the transformation towards cleaner energy. Article 9 of the Paris Agreement from 2015, a legally binding international treaty on climate change to limit global warming to below 2 degrees Celsius increase, stipulated in its funding, that developed countries will assist developing countries to fulfil their obligation in the treaty (United Nations, 2015).

An important consideration to be made regarding developing countries is the matter of financial problem. These countries often face more pressing issues than implementing sustainable energy systems, for example, economic growth and poverty alleviation. Often political conflicts and an overall lack of resources present insurmountable barriers in attaining sustainable infrastructure. The lack of practical support and availability of technical expertise aggravate the situation even further (Carla Delgado, 2019). This is where the energy system simulation software NESSI developed by S. Eckhoff and L. Vinke et al. and customized for the needs of developing countries by M. Hart, comes into place. The application aims to aid stakeholders in developing countries to make founded decisions about optimal energy systems at an evaluated location.

The software is developed within the MATLAB ecosystem, a licensed platform for programming and numeric calculations. While it is a great tool for most kinds of technical applications, in its actual form it drastically limits the reach and usability of the simulation software due to its limited accessibility. Moreover, it is bound to local machines or local networks. The utilization in developing countries can therefore be considered as highly unpracticable, which leads to the question if:

> *Evolving the simulation software NESSI into a web application renders it more applicable for its designated purpose in developing countries and increases its reach beyond the current scope.*

For this purpose, a web application on the framework of NESSI MATLAB was developed with the goal to make it available worldwide, to anybody, and for free. For that reason, the status quo in developing countries is researched with a focus on the possible requirements for a corresponding web application and the findings used to create a customized web application including detailed explanations and reasoning. Lastly, the application will be tested and evaluated within the scope of the current research.

8 Summary and Outlook

Most researchers with a focus on climate change and sustainable energy all report the same findings; Climate change is fuelled by the consummation of fossil energy sources due to its greenhouse gas emission and rising pollution levels pose hazards for the environment and humans alike. Sustainable energy can provide a remedy to the increasing threat of an inhabitable planet, but its implementation grows slowly and often financial interests and technical feasibility provide barriers that are hard to overcome. Global pacts like the Sustainable Energy Goals provide incentives.

Particularly in developing countries with their low-income and often rural and underdeveloped regions, implementation of renewable energy sources stagnates and conventional energy sources contribute by far the most to cover the energy demand. More developed countries, for example Thailand, created their own roadmaps to increase the share of sustainable energy in the overall energy portfolio. Nonetheless Thailand's energy needs are for now covered for now by around 90% fossil and only 10% renewable energy sources, which leaves ample room for improvements.

The problem-oriented decision support system NESSI can provide help by offering an extensive analysis of building energy systems, taking ecologic and economic factors into consideration. Stakeholders can use it to make predictions about the feasibility and ecological footprint and base their decision on simulated results. The encapsulation within the MATLAB ecosystem stifles the reach and accessibility of the application and changing the foundational framework from MATLAB to a more accessible solution can enhance it manifold. This is why within this thesis a web application was developed on basis of the NESSI MATLAB program.

Studies of internet availability and usage in developing countries, deemed a web-based version of NESSI feasible, as internet coverage reached 53% globally and 47% in developing countries, with an average global internet speed of 11Mbps. A web application would inarguably have a far greater scope that a MATLAB based program.

The approach taken to build this web application follows scientific guidelines for design and structure and provides a decision-flow to make taken paths and choices comprehensible and transparent. For its programming language, Next.js was used which is based on the popular front-end framework React, utilizing JavaScript as programming language and offers great performance and responsibility. With the insights gained from previous research, the application was optimized for developing countries in terms of mobile responsiveness, but also speed and low-data consumption with the help of Next.js's integrated features like Document Object Modelling. The finished app was then deployed to a server provided by the Leibniz

University Hannover, taking into account website security and legal requirements, where it is now (31.05.2021) accessible[1].

Ultimately a website utility testing was conducted including a user testing, mobile responsiveness testing and performance comparison against the MATLAB program to provide a scientific measure of performance. The user testing provided insights to the user-perspective of the general purpose and interface- and interaction design, which were throughout conceived very good. The mobile device usability was rated great, though for older and lower quality smartphone calculation time took up to 40 seconds. When compared against the MATLAB program, the web application outperformed the MATLAB program by about 50%.

Transferring NESSI into a web application is a big step, not only in terms of accessibility and expanding reach, but also for the general approach towards energy system simulation. As far as findings show, no to very little equally complex simulation systems have been introduced to the internet, NESSI may be the first of its kind. The potential of web applications is huge with the right hardware and the proper functionality. To further improve NESSI, more features, for example an interactive map on which to select the desired location from, could be implemented. Code improvements in terms of calculations and algorithms could improve speed and restructuring the code could lead to easier maintenance. With the early approach towards scientific web tools, NESSI might as well inspire the market and provide incentive for more research and development in web-based simulation systems.

[1] https://vm188111-iwi.hosting.uni-hannover.de/