Individual Assignment on Sustainable Development Goals: Optimization for Rural electrification

In the SA2001 edition in Autumn 2022 for students in the master's programme in Applied and Computational Mathematics (TTMAM) the learning activities centred around several final degree project reports from former students in TTMAM:

Ridenour, Jonathan, *Climate Impact Modeling of Hydrological Inflow into the Swedish Power Market*, 2016, (84 pages).

Paulus, Amanda, *A Model-Predictive-Control Based Smart-Grid Aggregator*, 2018, (58 pages).

Risberg, Daniel, *Robust Optimization in Seasonal Planning of Hydro Power Plants*, 2015 (72 pages).

Peters, Jorrit, *Dynamic Programming Heuristics for the Optimization of Hydropower Planning*, 2016 (70 pages).

The topics of all the four reports were connected to Sustainable Development Goal (SDG) 7: "*Ensure access to affordable, reliable, sustainable and modern energy for all*". However, the context for the final degree reports is primarily Swedish. In addition, for SDG 7, several policy documents and reports on trade-offs and synergies with other SDGs are available on https://sdgs.un.org/goals. The policy reports are typically focused on the world-wide progress per SDG and elaborate more on the interlinkages between the SDGs. However, the role of applied mathematics and computational mathematics, which is what we are looking for in this course, are often not explicitly seen or discussed in depth in those policy documents. Hence, their usefulness in learning activities is seen as limited.

To better understand the SDG 7, its interlinkages with other SDGs and with applied and computational mathematics, our literature survey found the following recent article (Dec 2021, with 170 references):

B. Akbasa, A. S. Kocamanb, D. Nockc, P. A. Trotter, *Rural electrification: An overview of optimization methods*, Renewable and Sustainable Energy Reviews, 156 (2022).

which is a so-called *review article* on the mathematical modelling of electrification in rural areas. In comparison with the final degree project reports by TTMAM students, the review article focuses more on all the four aspects of SDG 7: "*Ensure access to **affordable**, **reliable**, **sustainable** and **modern** energy for all*" in rural settings worldwide. This article will provide the basis for your individual and group assignments.

An even more recent review article (Jun 2023, with 160 references) is "*A state-of-the-art review and bibliometric analysis on the sizing optimization of off-grid hybrid renewable energy systems*". While this article has a good visualization of the field, see Fig. 1 in the article, and a clear overview of various indicators (Section 5: economic, environmental, social-political and energy-efficiency), we find that the article "*Rural electrification: An overview of optimization methods*" has a more clear connection to the SDGs and better describe the challenges (in section 7) that face an engineer who works with optimization of rural electrification.

Some feedback we got after the "intersectional design cards" seminar on Sep 8, 2023, was that the economic factor – which eventually may be the dominating factor – was not explicitly or clearly seen from the intersecting factors in the card deck. The topic of this week's assignments will focus more on the overall economic factor as the cost function for optimizing the rural electrification system often is the *monetary cost* of the system and the challenge of optimizing for conflicting requirements.

Individual reflection question 1

Read the whole article "*Rural electrification: An overview of optimization methods*" and then study Table 2 on pages 8 and 9. Reflect upon which of the many listed references/methods in Table 2 that you find most interesting.

Motivate, in the text box below, why you have selected the reference/method, e.g., (i) a reference/method that is trying to include most of "affordable", "reliable" and "sustainable" within SDG7, (ii) a reference/method trying to include other relevant SDGs besides SDG 7, (iii) a reference focusing on developing rural electrification in a specific country, etc.

Read quickly through your selected reference from Table 2, i.e., the article in the last column in Table 2, to gather more info on the optimization problem described in that article. Concentrate your reading on the Discussion and Conclusions sections of your selected article and summarize the main results in one paragraph in the text box below.

Since I do not have much more insight of the methods than provided by the article, my choices might not entirely reflect the desired outcome. However, I do not believe that one single method should be regarded as better than another. Because, when implementing a system there are probably more factors constraining a problem than what can be used as input for a single or even multiple optimisation techniques. There should be a reasonable combination of both several optimisation models, heuristic as well as meta heuristic approaches. Although, I think I would include the Genetic Algorithm, mostly due to flexibility compared to mathematical models, making it more affordable and able to handle more social factors, especially when considering more or less off grid renewable energy electrifications. However, a model such as Implicit Stochastic Optimisation, ISO, would also be of consideration, since it might be able to reflect the problem of the systems more accurately. Hence, my choice falls on ISO in this case. I want the model to be quite general or at least applicable to rural areas, although it is understandable different geographic locations has their own unique challenges. Also, considering that rural areas with lack of electrification are frequently located in areas of a large number of hours of sun light, I want photo voltaic to be the main system of focus. Although, it has to be stored somehow, so diesel, biogas or hydropower are also of interest. Thus, the article I choose is Viteri et al., 2019.

The article's main results are as follows. In order to improve Energy access in rural and coastal communities, photo voltaic together with battery storage were the most adequate result. Diesel was never a good enough alternative for being chosen by the model. The focus of the model was on rural areas in Colombia where the results are particularly relevant. This article supports the use of renewable energy as the best consideration for rural areas in Colombia when improving Energy accessibility. This choice is considered to be a cheaper alternative than diesel generators which often are used in rural communities. Thus, it is economically more attractive in a longer time perspective. In particular, PV systems in the span of 22 and 29 kWp together with battery storage between 74 and 93 kWh was the best option every time. Also, when a larger system is built, the frequency of interruptions are decreased. However, the choice of system always falls in the knees on "policy makers and investors". Thence, there are many thresholds to be climbed over for convincing them to make a good decision. One such incitement can be the economical factor, considering PV and batterys comparable cost and future gains. The model could be expanded to include a more diverse surrounding such as the " Environmental, human and social impacts".

Individual reflection question 2

Focus on the overall challenges on rural electrification in accordance with SDG 7 by selecting one of the following four subsections in the "*Discussion and future perspectives*" of the article "*Rural electrification: An overview of optimization methods*":

(1) Limited ability to fully address energy-enabled SDGs
(2) Limited coverage of integrated on-grid and off-grid approaches
(3) Limited usage of high-resolution technical, supply and demand data

(4) *Lack of complexity in mathematical optimization models for rural electrification*

Summarize in your own words your selected subsection and clearly describe your main take-aways in the text box below.

This is considering subsection (4) Lack of complexity in mathematical optimisation models for rural electrification.

Mathematical models shown by this article was mostly linear. As pointed out above, there can be multiple important factors that are being overseen by such a model. Thus, dynamic and non-linear programming can be of good use, however, not used in many of the referenced articles. Therefore, one main takeaway is the need of such research of the subject. The article also points out the need for researchers to present a comparison of time and quality for their optimised solutions, i.e., how the quality and time to get to the result relates. Furthermore, the article expresses the need for more continuous optimisation methods for deciding the geographic location of the systems. The need of stochastic optimisation is also important in order to predict the demand and possible interruptions of the systems, which might decrease the long-term cost.