Equitable Electricity System Planning in Developing Countries

Charles Van-Hein Sackey[1], Destenie Nock[2]

Carnegie Mellon University

1. cvanhein@andrew.cmu.edu 2. dnock@andrew.cmu.edu

Background and Motivation

- The pursuit of self-reliance and stability is at the heart of the development of every society, especially developing countries. Given the ubiquitous presence of technology around the world, access to electricity has become a major driver of development in sub-Sahara African countries, such as Liberia.
- United Nations (UN) aims to achieve universal access to affordable, reliable, sustainable and modern energy in Goal 7 of its Sustainable Development Goals (SDGs).
- Our maximizes the benefit consumers derive from use of electricity bounded by a budget constraint, while accounting for various stakeholders' preference for equality in electricity capacity planning.

Goal 7:
Ensure access to affordable, reliable, sustainable and modern energy for all.

Case Study: Liberia

- Liberia was used as a case study for using this model to plan electricity capacity expansion. Liberia was chosen due to its current status as a developing country in sub-Sahara Africa, and the availability of electricity data and other pertinent information about the country.
- The information below provides a snapshot of the country of Liberia:
  - Population: 4.8 million
  - Capital: Monrovia
  - GDP (per capita): $6.1 billion ($1,300)
  - Electricity Access Rate: 19%

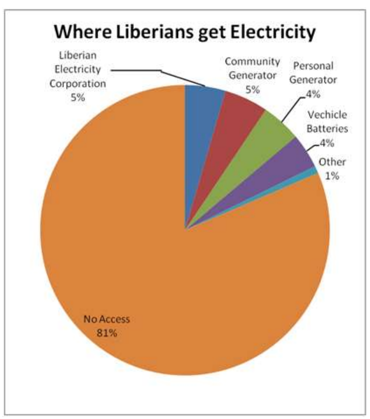


Figure 1: Liberia Sources of Electricity

Model Development

- The objective of this model is to maximize the utility consumers gain from electricity subject to physical constraints on network flow and budget constraints on the total cost power system expansion and operation. Electricity access is measured as the maximum amount of electricity available per capita electricity consumption. The overall methodology for this work is presented in Figure 2
- The mathematical formulation of the optimization model (with select constraints) is as follows:
- Maximize the utility of the stakeholder: $U(\mathbf{x},\mathbf{p}) = \sum_{i \in I} u(x_i, p_i)$

Stakeholder Utility = Sum of Utility (or happiness) they get from each node

Such that

$$\sum_{(i,j)\in E}\left(C^{T,L}d_{i,j} * e^{L}_{i,j} + C^{T,H}d_{i,j} * e^{H}_{i,j}\right) + \sum_{i\in I, k\in K}\left(C_k^{F} G_{i,k} + C_k^{V} g_{i,k}\right) \le B$$

Transmission Costs + Generation Costs ≤ Budget

$$x_i \le g_i + \sum_{j\in N} f_{j,i} - \sum_{j\in N} f_{i,j}$$

Electricity at node i ≤ Generation at node i + Flow into node i – Flow out of node i

$$g_i \le \sum_{i\in I, k\in K_i} g_{i,k}$$

Generation at node i ≤ Sum of all generation sources at node i

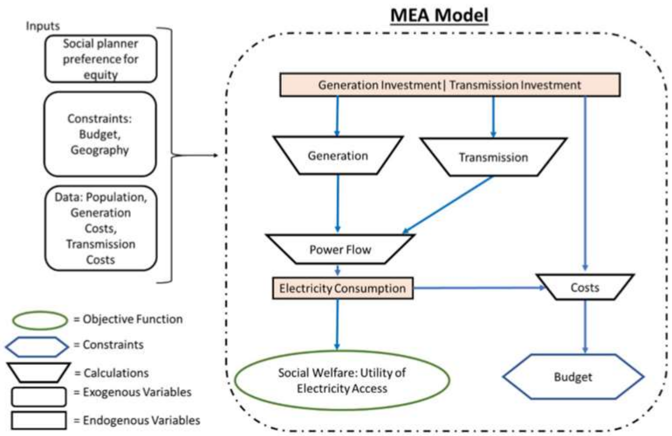


Figure 2: MEA Model

Model Expansion

- Future work involves building a multi period optimization model as seen in Figure 3. In the first stage we would take into account equality preferences, and in the second stage we would take into account cost constraints.

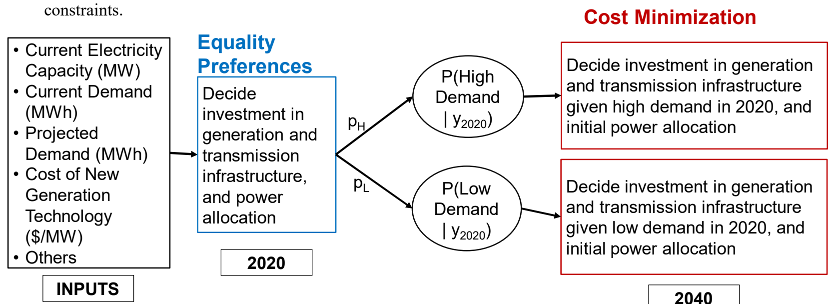
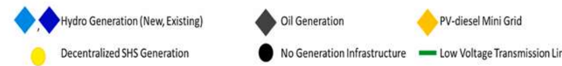


Figure 3: Flowchart for future model

Results

- A higher stakeholder preference for equity resulted in higher rural electrification rates with lower total consumption, while a lower preference for equity resulted in higher urban electrification rates (and lower rural electrification rates) .
- The following figures illustrate the capacity expansion plan at $10 million/ year for 30 years based on varying a low and high equality preference (Figures 4 and 5, respectively)



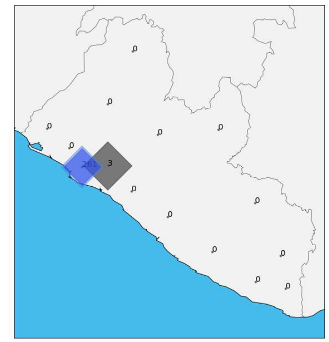


Figure 4: Low Equality Preference

Figure 5: High Equality Preference

Conclusions

- Equality preferences are very important for understanding if we will reach the universal access target.
- A failure to incorporate equality preferences may mean that we never reach the UN SDG 7

Acknowledgements

This work is partially supported by the National Science Foundation Graduate Research Fellowship under Grant No. 1451512.

References

- CIA World Factbook: Liberia, 2019. https://www.cia.gov/library/publications/the-world-factbook/geos/print_li.html
- Nock, D., Baker, E., Levin, T. Changing the policy paradigm: A benefit maximization approach to electricity planning in developing countries. Applied Energy 264 (114583), **2020**.