**Title: Two level network design model and its application in electrification**

**Stakeholders**: PIU, EASP (WB)

**Theory of Change:** In the context of electrification and grid extension, it is essential for public and private sectors to prioritize investments wisely within the available funding. One key consideration is identifying areas with lower per-customer connection costs. This work designs a national-level distribution network system. Due to varying settlement patterns, the lengths of per-customer medium-voltage and low-voltage lines and the number of customers per transformer differ. By analyzing these factors, we identify areas with lower per-customer connection costs, thereby determining development priorities and ensuring efficient resource allocation.

Published paper link: [https://doi.org/10.1016/j.esd.2020.12.005](https://doi.org/10.1016/j.esd.2020.12.005) .

Simone Fobi and Ayse Selin Kocaman, under the supervision of Professor Vijay Modi, developed the two-level network design algorithm. This algorithm inputs household locations and optimizes the total connection costs, to determine transformer placements and low-voltage (LV) and medium-voltage (MV) networks connecting all households. In the preprocessing phase to identify households locations in rural areas, a merging process is implemented to address the issue of multiple structures per household, where structures are often identified from satellite data. This process aims to align merged households with actual household counts from the district-level census.

The figure from the paper illustrates a computed network for a section of a ward in Kenya, effectively demonstrating the model's capabilities. It highlights varying settlement patterns within the ward, where some transformers connect to more households (upper left transformers in (b)) while others serve fewer (transformers on the right edge in (b)). This variation significantly impacts electrification costs and levels, particularly in rural areas. Nucleated settlements are more likely to have transformers compared to spread-out ones due to shorter required electric lines and fewer transformers, even if these two regions have the same population density.

Consequently, one application of this algorithm is to provide a metric that represents settlement patterns, derived from transformer locations and associated metadata, including the number of connected households, average LV length per household, distance to the farthest connected structure, and proximity to adjacent transformers. This allows for clustering of households based on electricity grid network considerations, effectively indicating different settlement patterns. As shown in Fig. 2, different wards in Kenya have different connection metrics as depicted in (a)-(c), with the total estimated costs summarized as the overall metric in (d).

The two-level network design is applicable not only to regional grid connections but also to mini-grid network designs. It calculates the average distribution costs per household, assessing the economic viability of establishing mini-grid connections based on geographic locations. Further decisions can be added, such as excluding distant customers where the connection is not economical and opting instead for standalone systems.

Overall, this study develops network design algorithm and showcases how different areas might benefit from different electrification strategies, whether through grid extensions, mini-grids, or stand-alone systems.

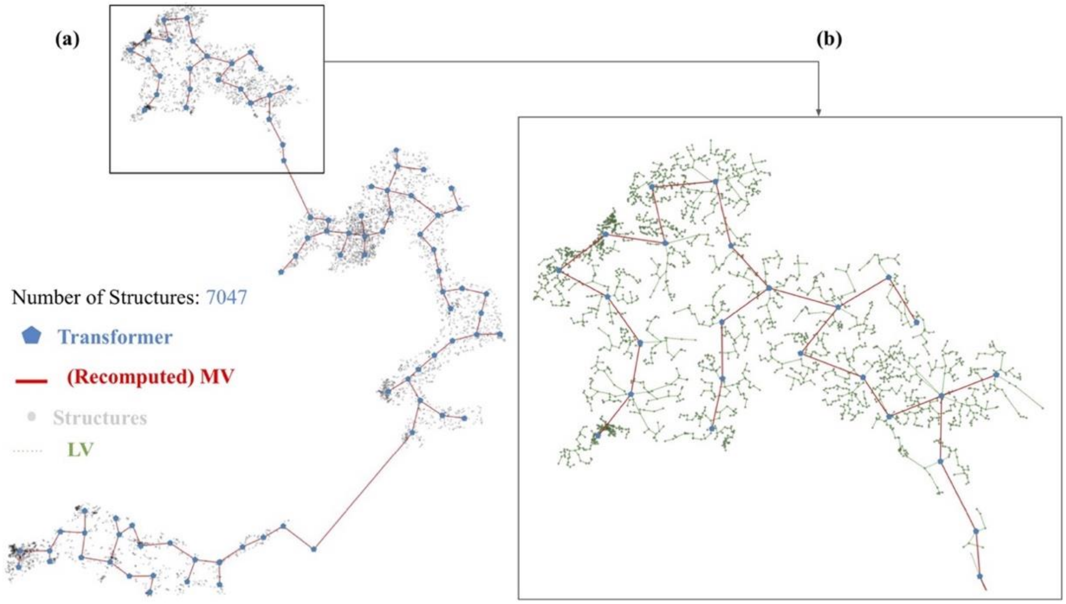


**Fig. 1.** Complete network for a sample ward with 7047 structures. Figure (a) shows transformer placement and the MV network connecting the transformers. Figure (b) includes the LV network for a small section of the ward, showing connections between structures and transformers.

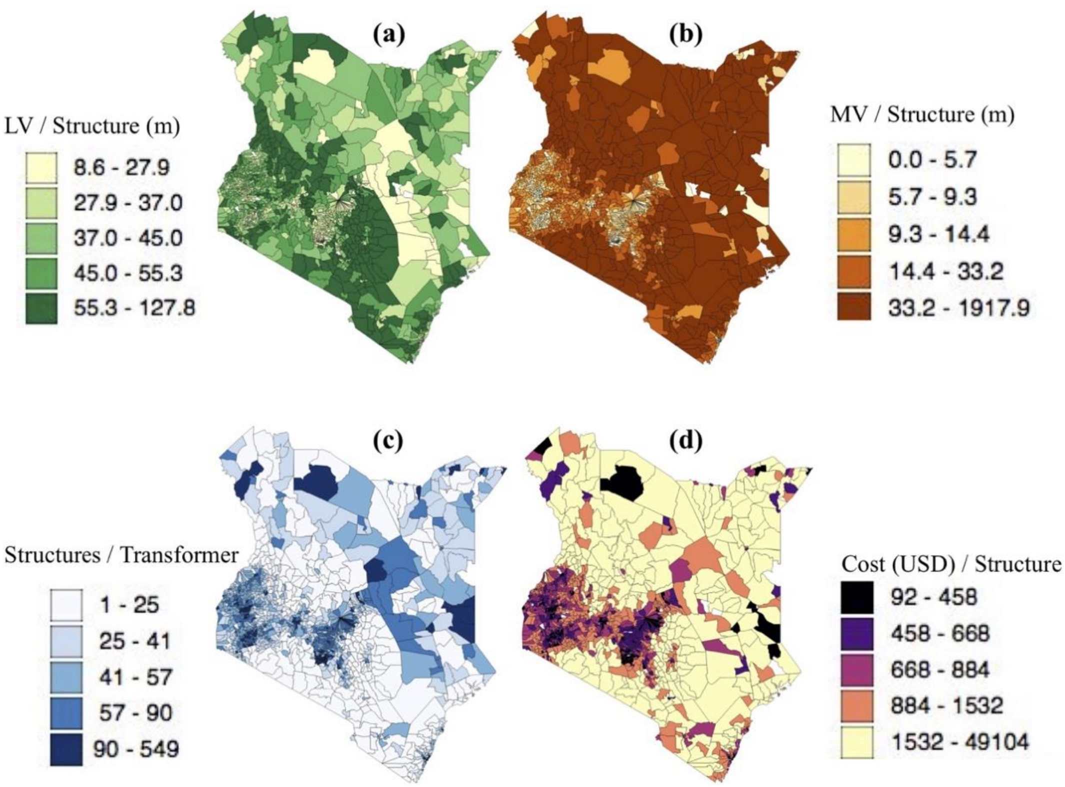


**Fig. 2.** Average ward connectivity metrics for Kenya by decile.