Rural Electrification in South Africa: Design Challenges, Considerations and Choices

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Scope

This project examined rural electrification in South Africa focusing on the design of hybrid off-grid electric systems.

Background

A rapid electrification program in South Africa saw three million new electric connections made in the 1990s[1], leading to a doubling in electricity demand[2]. However, the generation capacity did not increase at the same rate which resulted in increasing numbers of unplanned blackouts in the 2000s. The overarching theme is not to determine exact system configurations which can be implemented, but rather to determine the methods and information that is needed to find potential system configurations.

Methods Overview

A rural electrification project consists of multiple steps which are site selection, load prediction, resource assessment, technology selection, and finally system configuration. Figure 1 provides a visual overview of the design process, with purple boxes representing collected data, orange boxes representing computational software or methods used, and the green boxes representing the outputs.

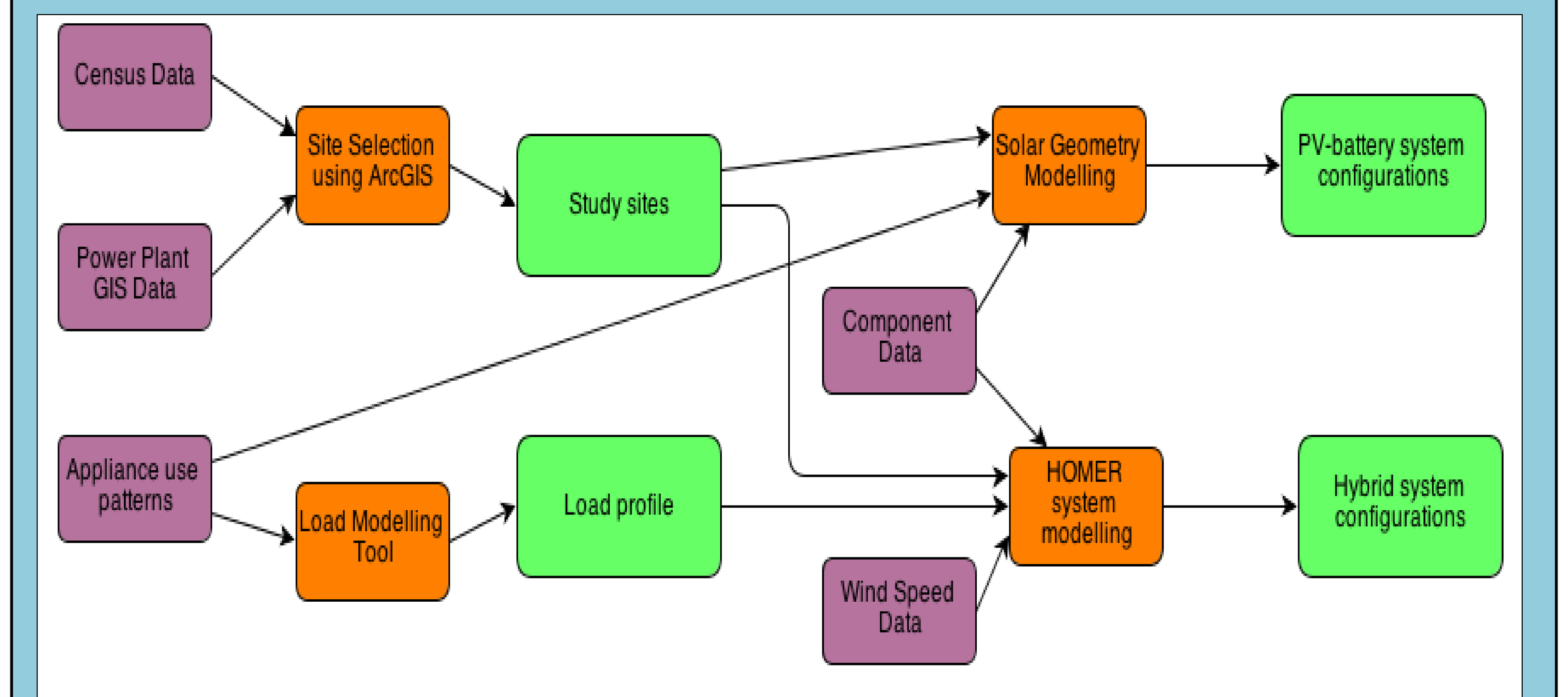

Figure 1. Chart showing how the input data relates to the tools developed and used

The choice of site shapes the rest of the project and a model to identify potential sites was built in ArcGIS. Load prediction was done by using a load modelling tool developed in MATLAB. Resource assessment requires finding the wind and solar resources at the site in question, while technology selection involved finding manufacturers of the technologies used in the systems. Possible system configurations were found using two models, through HOMER software and the other was a model based on solar geometry.

Acknowledgements

Thanks go to Judith Cardell, my thesis advisor, and to Denise McKahn, my second reader for their invaluable feedback and to Jon Caris for the help with ArcGIS.

References

[1]Bekker, B., Eberhard, A., Gaunt, T., & Marquard, A. (2008). South Africa's rapid electrification programme: Policy, institutional, planning, financing and technical innovations. *Energy Policy*, *36*(8), 3125-3137

[2]Department of Minerals and Energy. (2008). In Eskom (Ed.), *National response to South Africa's electricity shortage*

Site Selection

Site selection was carried out using ArcGIS software in combination with South African census data and GIS data about South African power plants. The site selection model finds potential sites based on criteria such as the distance from urban centres and the fraction of households that already use electricity for lighting, and the entire model is shown in Figure 2, with the results shown in Figure 3.

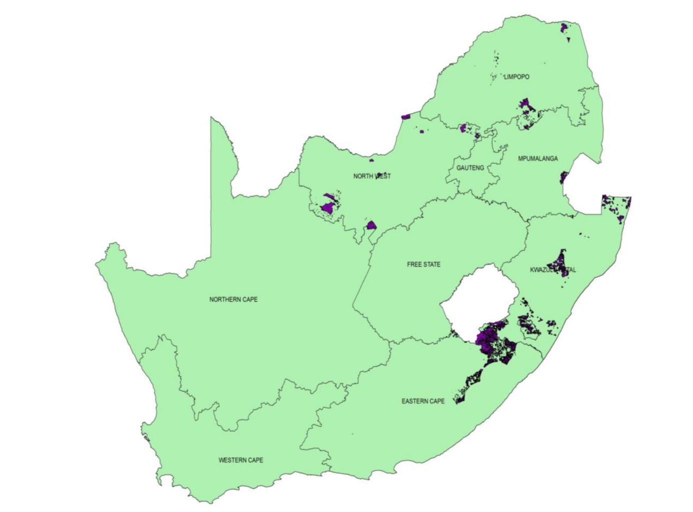

Figure 2. Selected sites shown in purple

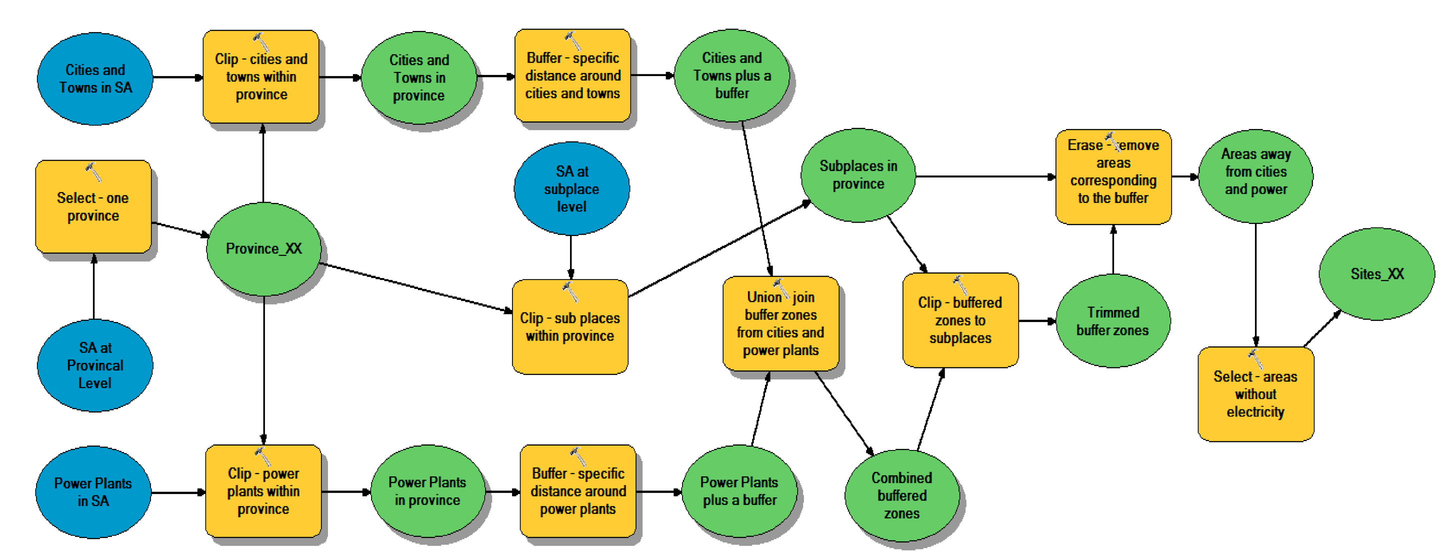

Figure 3. Flow chart showing the site selection model from ArcGIS

Load Profile Modelling

A load profile modelling tool was developed using MATLAB, which included elements to account for day-to-day variation. Two different levels of load were considered, one very low level which has minimal appliances and another which added more energy intensive appliances. The appliances at the high load level are shown in Table 1 below. Figure 4 shows the load profile for one household over one week, showing the daily variation.

Table 1. Appliances used in one household

Appliance	Power (W)	Num	WD num uses	WD length used	Intervals of use on WD	WE num uses	WE length used	Intervals of use on WE
Lights	30	6	2	3	05:00 to 09:00 & 17:00 to 00:00	2	3	05:00 to 09:00 & 17:00 to 00:00
Cellphone Charger	10	1	1	2	18:00 to 00:00	1	2	18:00 to 00:00
Television	80	1	1	2	18:00 to 23:00	2	3	09:00 to 13:00 & 16:00 to 24:00
Microwave	200	1	2	1	06:00 to 08:00 & 18:00 to 20:00	3	1	06:00 to 08:00 & 13:00 to 15:00 & 18:00 to 20:00
Fridge	250	1	1	24	00:00 to 00:00	1	24	00:00 to 00:00

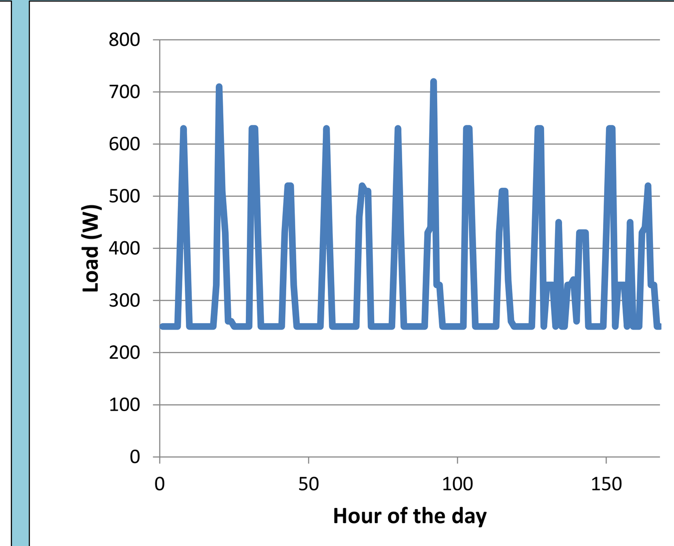

Figure 4. Load profile for one household

HOMER Modelling

HOMER (hybrid optimization model for electric renewables requires a large number of inputs including the solar and wind resources at the site, the fuel prices, system constraints, interest rate, and technical specifications for all components. Each component has to be specified, detailing capital cost, maintenance cost, replacement costs, and different sizes to consider. For each site six different simulations were run pertaining to different load levels and different levels of load aggregation. A simulation was also run to study how the price of diesel affects the overall system configurations, with the historical diesel price shown in Figure 5.

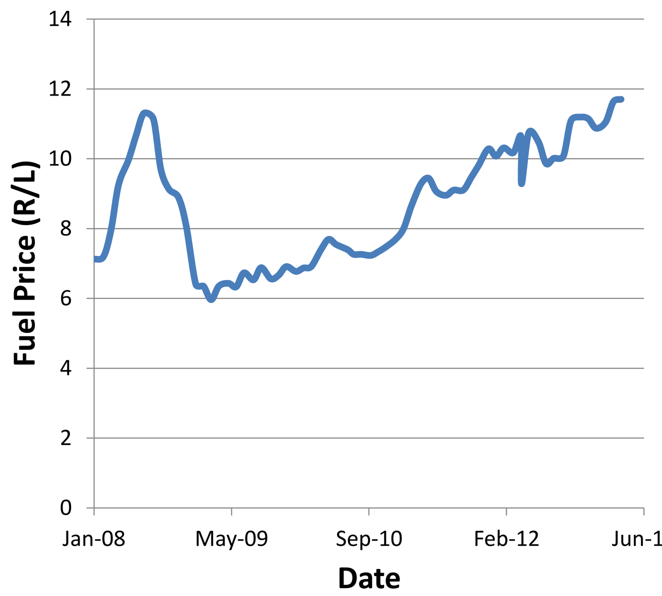

Figure 5. Price of diesel over the last five years

At all sites, and all load levels, as the level of aggregation increases, the capital cost per user drops, which is shown in Figure 6. Table 2 shows a fraction of the results from the original simulation for one site, while Table 3 shows how those results changed when the price of diesel increased to R15.00/*l*. The PV array size increased to offset the increased fuel costs, but despite this the NPC (net present cost) rose by roughly 13 percent.

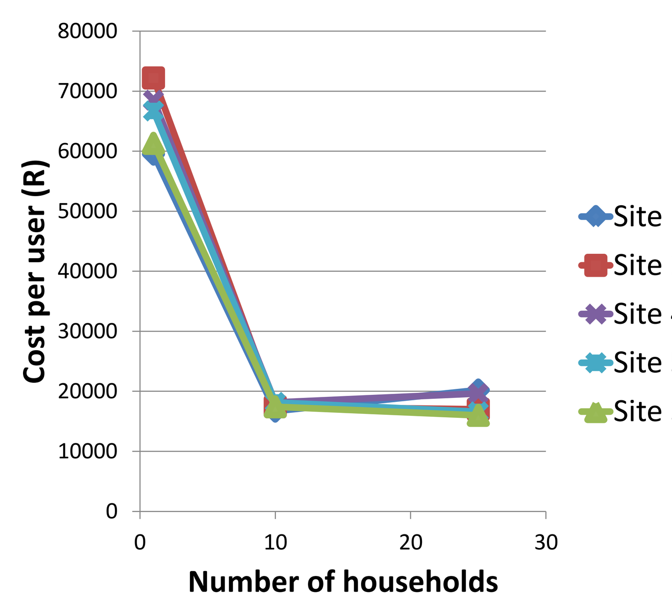

Figure 6. Results of load aggregation

Table 2. Simulation results for one site with diesel cost at R11.60/*l*

Site	PV	e230i	H3000	RA12-260D	Converter	Total Capital Cost	Total NPC	Operating Cost	COE
#	kW		kW		kW	R	R	R/yr	R/kWh
5	7.2	0	2.7	11	4.8	181,466	1,235,495	84,578	3.658
5	6.6	1	2.7	11	4.8	192,383	1,240,247	84,083	3.705
5	9	0	2.7	11	4.8	203,066	1,255,552	84,454	3.623
5	8.7	1	2.7	11	4.8	217,583	1,268,582	84,335	3.658
5	10.2	0	5.4	17	4.2	245,927	1,453,849	96,927	4.061

Table 3. Simulation results for one site with diesel cost at R15.00/*l*

Site	PV	e230i	H3000	RA12-260D	Converter	Total Capital Cost	Total NPC	Operating Cost	COE
#	kW		kW		kW	$	$	$/yr	$/kWh
5	11.4	0	2.7	11	6	241,436	1,419,258	94,511	4.207
5	10.2	1	2.7	11	6	245,153	1,430,882	95,146	4.258
5	12.6	0	5.4	25	4.8	317,176	1,603,772	103,240	4.48
5	12.6	0	5.4	25	4.8	317,176	1,603,772	103,240	4.48
5	12.6	1	5.4	25	4.8	335,293	1,611,386	102,397	4.501

Conclusions and Future Work

The final system configurations obtained from these models show that rural electrification using hybrid off-grid systems will benefit residents. The best options involve setting up multiple household systems as that reduces the cost for the individual households by 200% compared to setting up an individual system for each household.

- Adding functionality of the load profile tool to increase modelled variability
- Finding more components to better match the electric demand
- Simulating the system designs for other levels of aggregation
- Better quantifying installation and maintenance costs for these systems