Electrification in South Africa: a prospective plan to maximize social benefit by prioritizing electricity investments

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The present paper provides policymakers with an evidence-based plan to allocate electrification investments where social benefit is maximized.

South Africa (SA) faces increasing challenges in bringing affordable and reliable energy to its population because of insufficient installed capacity, transmission infrastructure, and insufficient funding. Most of the previous electrification analyses center only on increasing investment levels beyond SA's current budgetary restrictions. I fill previous analytical gaps by changing the traditional paradigm of investment allocation: SA's limited budgetary resources must be spatially allocated in places where social benefits are maximized across provinces and municipalities. To maximize social benefits, it is essential to include the findings of previous empirical evidence: electrification projects in SA increased employment per household and contributed to reduce poverty. As a result, I present an electrification plan to allow SA to continue closing its electrification gaps and simultaneously creating a conducive environment to reducing unemployment.

Background and Summary

SA faces increasing challenges to fulfill its Sustainable Development Goal (SDG #7) to bring affordable and reliable energy to its population. The Sustainable Development 2022 Report shows that relative to 2019, SA in 2022 is decreasing its ability to close electrification gaps: 16% of its population remains without electricity since the 2000s (Tracking SDG7, 2020), and is currently facing an unreliable electricity supply more frequently. Current challenges are exemplified by a record number of outages in 2022 due to grid overload from lack of energy generation and increasing demand for electricity services (Bloomberg, 2022).

An important part of understanding SA's electrification challenges requires observing electrification inequalities over space. Falchetta's electrification tiers (Falchetta, 2019) (Fig. 1) show that most of the people facing low electrification consumption -- for example, in Gauteng, one of SA's most populated provinces -- are in the outskirts of SA's urban centers: the lowest consumption tier 1 is on the borders of the urban center (borders colored in blue and green in Figure 1). This consumption tier represents the people who belong to the bottom quartiles of electricity consumption measured by nightlight radiance from 2014-2018. Complementary, The High-Resolution Settlement Layer for 2015 (CIESIN, 2015) (Figure 3 below) shows the complexity of providing electricity for a considerable part of the population. The way that this population is sparsely distributed over SA's territory makes the cost of transmission an electrification constraint.

Based on the insight provided by the previous maps, electrification efforts in SA face policymakers with the difficult decision of allocating limited resources for communities that are dispersed across considerable distances. When planning, policymakers can commit mistakes in allocating electrification resources in places where the capital cost is high and social benefits are small. Therefore, I provide evidence of where electrification should be allocated by mapping the place where unemployment is greatly affecting a considerable portion of the population.

Electrification has a direct impact on increasing the employment opportunities for a household because of its impact on productivity for rural communities or simply because it enables access to internet, providing better information for households. However, labor markets, which are essential to reducing monetary poverty, have struggled in SA to create sufficient jobs, particularly among the poorest quintiles. Even before the COVID-19 pandemic, SA's economy was showing serious challenges in creating sufficient jobs in a period where global markets were beneficial for SA's exports, and Foreign Direct Investment: between 2015 and 2017, unemployment varied from 25.1% to 27.7% (World Bank, 2018). Nowadays, after suffering the pandemic's aftermaths, SA has reached a new unemployment record with a positive trend (increment in 2 percentage points) and a higher rate of 35.3% (Reuters, 2022).

Closing SDG 7 gaps in SA presents the opportunity to rethink solutions to address the structural unemployment challenges in SA. These solutions are primarily spatial because of the legacies of inequality: the economy is having more difficulty in creating jobs (that might reduce poverty) in those areas where the Apartheid forced people to live far from arable lands or urban centers. Millions of South Africans are living on the city outskirts and rural areas because of the legacies of discrimination. The World Bank's (2021) recent evidence analyzing sources of inequality in SA shows that location in SA has a strong relationship with the inequality of opportunity, which refers to the level of access to education and health opportunities. Inequality of opportunity in South Africa contributes to explaining almost half of the inequality in consumption per capita (World Bank, 2021). In education alone, without proper electrification access, students from marginalized regions are probably studying less hours and receiving less access to the internet, which has a negative impact on their literacy attainment and probably in their long-term earnings.

Considering the spatial interaction between poverty, inequality, and unemployment, electrification efforts must enhance the population's probability to experience greater levels of employment by offering greater possibilities of human development to targeted regions. Previous evidence suggests how electrification had a causal impact on SA's employment. Dinkelman's (2011) research identified a causal relationship between places where an electricity project was rolled-out and increments in female employment equivalent to 9 - 9.5 percentage points. An important caveat of Dinkelman's findings is that women's wages did not increase in regions where employment increased. Therefore, electrification plans must be accompanied by additional policies that help marginalized communities to take advantage of an increased electricity supply.

In addition to Dinkelman's findings, Mesah's (2018) estimates suggest that the low electricity reliability reduces the probability of an individual being employed by between 35% and 41%. This employment probability is concentrated in high-skilled wage employments, which might have a broader impact over other sectors considering the aggregate of a country's competitiveness losses.

I used the presented evidence to create an electrification plan that targets regions where social benefit is maximized. By implementing this employment-based electrification, SA has the potential to create the conditions to reduce poverty and inequality.

Electrification that maximizes the social benefit

The present chapter describes how in using a geographical analysis, I was able to identify social-maximizing electrification strategies across SA's provinces. The following paragraphs briefly describe in detail the methods and results:

Step 1: employment risk and initial insights about electrification plans

The first step consisted in interpolating 2016 DHS GIS data that contained employment status per women head of cluster. This interpolation was necessary because of the data gaps in employment data at the subnational level in SA. First, I summed the total number of women classified in the survey as "currently employed" per each DHS cluster. Using the total number of employed women per cluster, an employment risk rate was calculated by dividing by the total number of women per cluster. The previous employment risk rate per cluster was multiplied by the population information provided by the HRSL to calculate an estimated number of employed people at subnational level. Using the unemployment risk per DHS cluster, a surface of unemployment risk was estimated by performing a spatial interpolation that provides a representation of employment (Figure 2).

Fig.1: Electricity consumption tiers in South Africa

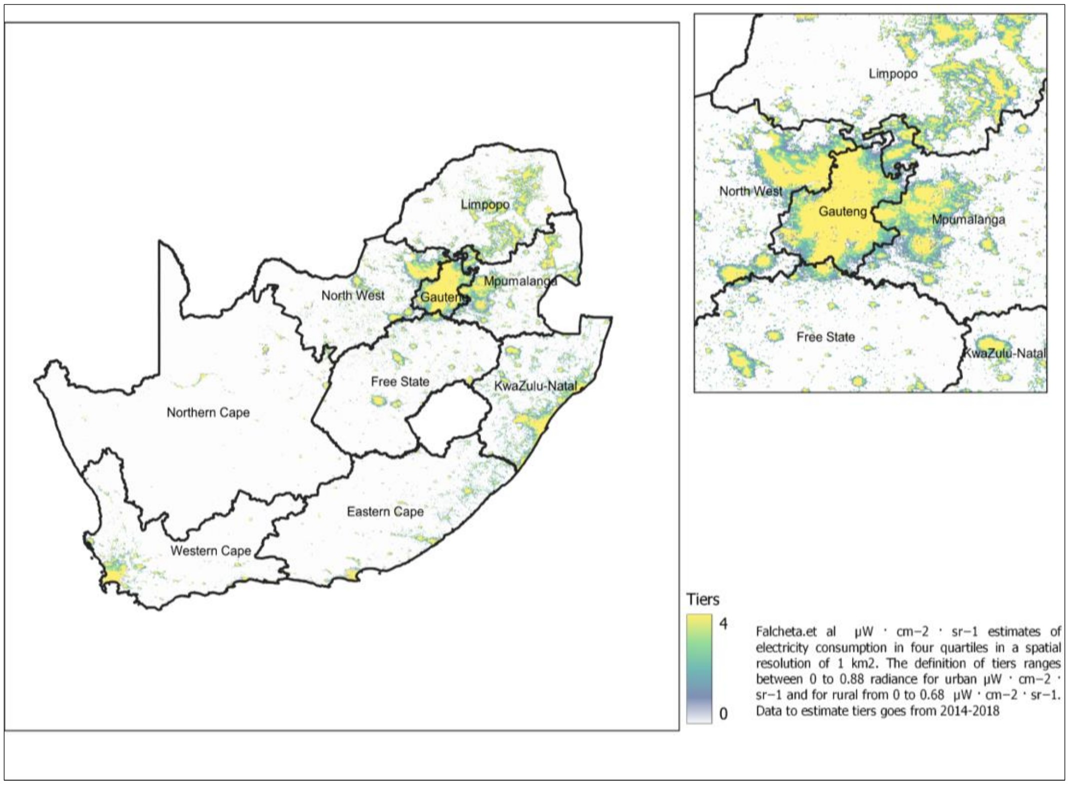


Fig. 2 Employment interpolation risk in South Africa

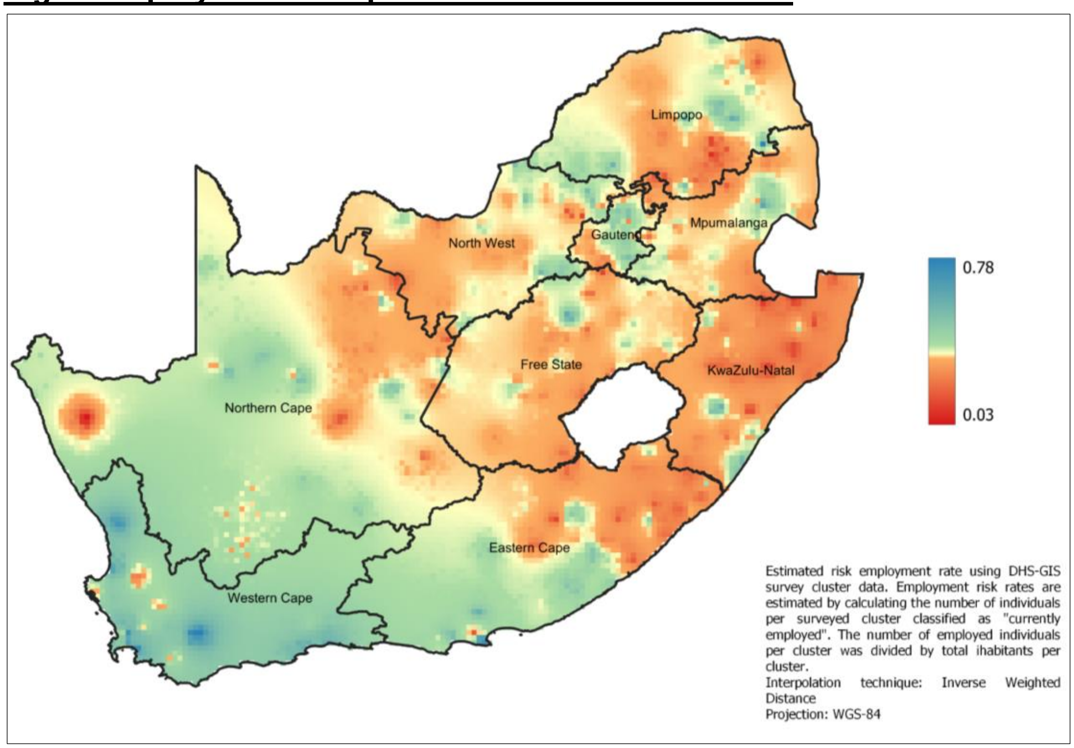
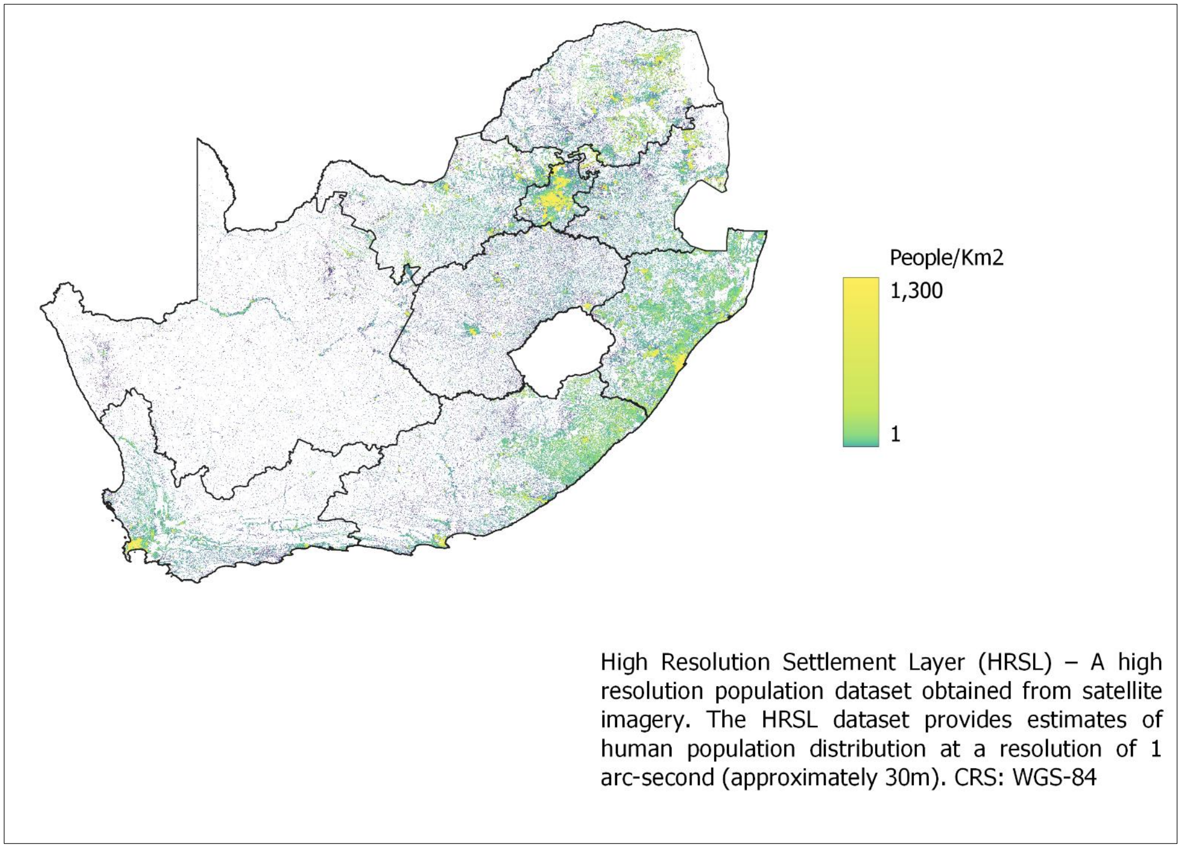


Fig. 3 High-Resolution Settlement Layer



For the case of KwaZulu-Natal, there is a high electrification consumption (as expected) concentrated in the urban center. The population distribution (see Figure 3) and the employment interpolation risk offer a relevant insight: KwaZulu-Natal presents the lowest employment, and its population distribution presents a strong concentration of dispersed population cluster. For this reason, a priori, is likely that transmission cost is higher relative to other provinces, which, in principle, might suggest that a decentralized electricity strategy would be a good fit for this province.

Second, in the case of Gauteng's province—the region with the highest population density according to HRSL—electrification efforts seem not to require intensive investments in transmission lines in comparison to KwaZulu-Natal considering that employment risk and electrification low tiers are less disperse spatially. Although, given the challenges of increasing outages. For this reason, it is possible that electricity generation investment is required in this province, which would increase electrification costs considerably.

Finally, the region of Northern, Western, and Eastern Cape presents low employment risks because of their low population living in dispersed clusters around urban centers. Also, Eastern Cape has a similar spatial distribution for its population in comparison to KwaZulu-Natal which initially suggests high costs in transmission investments for grid electricity

Step 2: Merging datasets

Step one layers, employment risk (Figure 2), and electricity consumption (Figure 1), were merged per municipality province using STATA 17 and QGIS raster analysis tools. Step 1 provided a general intuition of how unemployment could be addressed by connecting communities considering the spatial distribution of population density, employment risk, and electricity consumption. However, the information from step 1 did not provide specific cost information to guide the decision process of allocating electricity investments based on the discussed factors.

Once tabular information containing employment risk and electricity consumption per municipality is gathered, the next step consisted in using the Global Electrification Platform dataset (GEP, 2022). This dataset allowed me to join the previous dataset with investments in grid and off-grid electricity infrastructure to accomplish SDG 7 by 2030. As a result, the final dataset contained in each row a geolocalized electrification project associated with its grid cost (from high and middle voltage transmission lines), off-grid costs discriminated by several types of micro-grids, employment risk, employed population, and a penalty grid index that essentially reflects all costs associated with a grid electrification project.

Step 3: Quartile classification and priority index calculation

The previous step allowed me to have in one dataset a municipality's employment risk, electric consumption tiers, grid electrification costs, and off-grid electrification cost per each potential electrification project at a geolocalized point in SA. As a result, in order to know what regions in the short-term and long-term should be connected given their social maximizing effect over employment, a prioritary electrification index was calculated using the following criteria:

- Employed population: this was calculated in step 1 by multiplying employment risk times estimated population. This variable was classified in quartiles. The regions classified in the bottom employment quartile were recoded with a categorical value of 4 implying that these regions were more relevant given their higher levels of unemployment. The remaining regions were classified in a descending order using the remaining categories from 1 to 3.
- Penalty grid: GEP dataset contained a penalty grid index that classified each future electrification project with values ranging from 1 to 4. Regions classified with 1 represent a cheaper electrification project relative to other regions. Regions classified with 1 were re-coded with 4, which means that these regions should be considered as priority given their low electrification cost.
- Electricity consumption tiers: Falchetta's consumption tiers were classified within a range of 1-4, where 1 means regions with low or no electricity consumption, and where 4 means regions with high electricity consumption. Regions of interest correspond to places where electricity consumption is low (tier 1). Therefore, regions with tier 1 electricity consumption were assigned with a 4 in order to elevate their importance given that these regions are probably disconnected from the grid or suffering more outages in comparison to other regions.
- Budget limit variable: South Africa's National Treasury Report and World Bank's GEP (2022) estimated investments in electric grid extension is equivalent to 7.7 billion dollars to achieve SDG 7 electrification goals. This variable is useful to define how many electrification projects are achievable giving budgetary limits.

The prioritization index was created by summing the value of the previous four variables: those projects, with a total of 16 points, represent strategic investments because of their potential to bring electricity to an important number of South Africans, and to maximize employment at the minimum possible cost. Selecting projects where the prioritization index was equal to 16 points represented only 15% of the total universe of possible electric projects. As a result, the projects classified with 15 were included in the priority list, which increased proportion of projects to 40% of the total electrification projects.

Electrification plan

The priority investment index, Table 1, contains the total cost per province for both grid and off-grid project that maximize social benefit. Results from the prioritization index would allow 40% of the population without electricity to become connected.

The associated cost of connecting 40% of people experiencing low consumption of electricity or no consumption at all was calculated by selecting only the regions whose priority index was equal to the maximum priority possible: 15 and 16 out of 16 possible points in the prioritization index. Additional projects were added to the prioritized index if the accumulated cost was below the budget constraint of 7.7 billion USD.

The first two columns of Table 1 indicate the most convenient period to execute electrification investments per province. In a first installment (second column, last row), $522 million should be invested before 2025 both for grid solutions, such as lines of high medium voltage transmission, substations, and transformers. In a second installment (last row of first column), $537 million should be set aside for priority investments after 2025. The rationale for dividing investments into the periods before and after 2025 is because of the electricity generation challenges in several provinces. For certain regions, it would not be enough to connect them to the closest grid substation because most the substations are far enough that transmission costs become highly expensive. As a result, regions with larger generation deficits using a quintile classification were still considered as priority, but their grid investments should be deferred after 2025 because of their electricity generation challenges.

Results for Table 1 indicate that grid electrification investments should be allocated primarily in Gauteng province (60%), Mpumalanga (18%), KwaZulu-Natal (17%), and Limpopo (5%). Provinces. Furthermore, the remaining provinces, Northern, Western, and East Cape, should emphasize in off-grid electrification through photovoltaic and wind hybrid mini-grids' solutions.

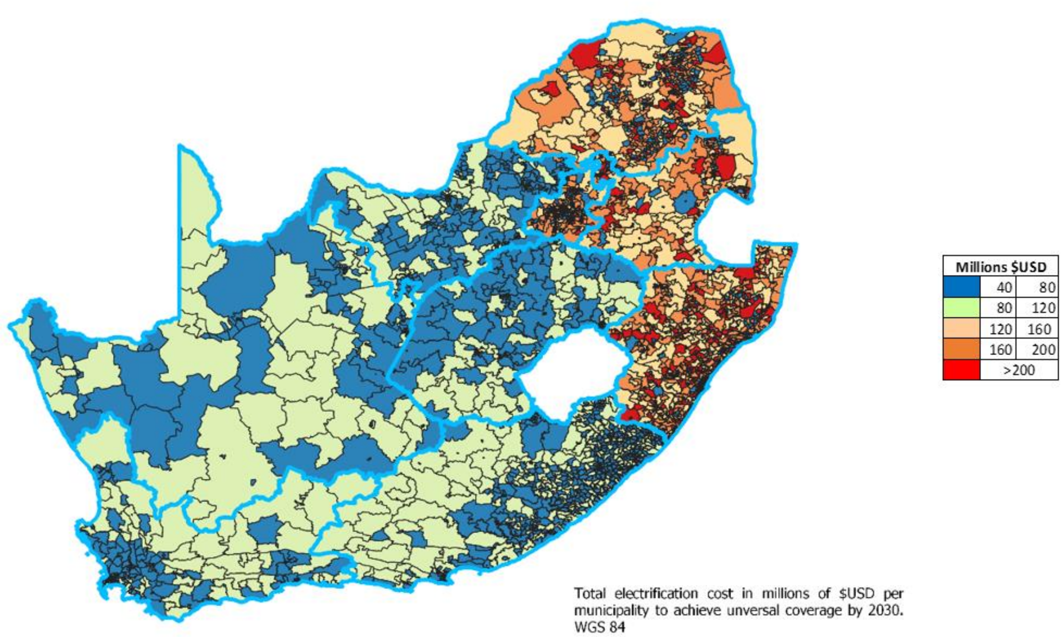
Table 1: Connection and generation investments-based prioritization index–only 15 and 16. ($ USD)

Province	Investments after 2025	Investments before 2025	% Minigrid-Photovoltaic (hybrid)	% Minigrid-Wind (hybrid)
Eastern	-	-	13,511,525	1,180,567
Free	-	-	3,941,313	944,447
Gauteng	321,869,320	304,720,283	104,924,386	104,983,742
KwaZulu-Natal	89,725,109	92,308,344	411,844,272	411,899,687
Limpopo	28,005,589	27,823,947	76,864,957	76,924,728
Mpumalanga	97,757,397	97,393,301	217,625,411	217,697,793
North	-	-	1,212,947	708,335
Northern	-	-	633,382	472,223
Western	-	-	17,269,095	590,281
Grand Total	537,357,525	522,245,984	847,827,287	815,401,803

Source: own elaboration with cost data provided by World Bank GEP

The previous investment cost can be observed in more granulated scale in Figure 4.

Figure 4: Priority investments per municipality in South Africa



Source: own elaboration

Results from Table 1 suggest that the total investment in priority electrification projects between 2023 and 2030 is worth $2.7 billion USD. In other words, by investing 35% of the total investment suggested by the Word Bank GEP platform, South Africa can provide electricity to 40% of people facing high unemployment and low electricity consumption at the cheapest cost possible.

Table 2 illustrates the two typical cases of investments' distribution per each municipality in two of the provinces with the largest cost. Gauteng concentrates a large population in a relatively small area. Migration processes in Gauteng, around urban centers like Johannesburg, created a considerable demand for electricity in challenging geographical areas for electrification. On the other side, KwaZulu-Natal presents a more difficult electrification case (similar to challenges of electrifying in Limpopo and Mpumalanga), because of the disperse population distribution in a larger area relative to other provinces. For this reason, this province has higher costs related to off-grid solutions.

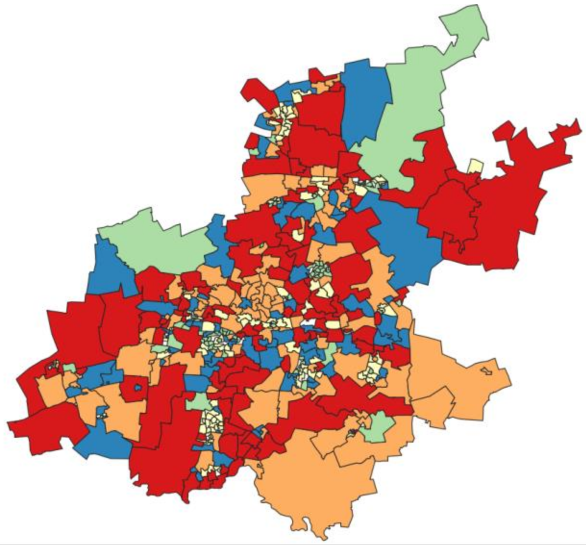
Policy recommendation

The previous plan delivers a general message to electrify SA using its outdated infrastructure: places with high population concentrations should be connected to the grid by investing in transmission infrastructure. Complementarily, distant, and geographically challenging regions require investments in decentralized solutions. The central piece of these decentralized solutions are mini-grids that should be implemented in public-private schemes. These public-private schemes should offer incentives to the private sector to participate in joint operations building infrastructure projects, such as mini-grid.

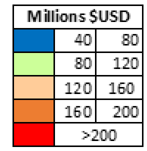
SA faces a budgetary deficit of $1.2 USD billions, according to SA's 2022 budget for electric infrastructure. The investments of SA's budget in 2022 are equivalent to $1.5 billion of USD versus what I suggest in this electrification plan: $2.7 billion USD. The main different between my electrification plan and the government's planned investments is that my budget includes connecting prioritized regions through off-grid solutions. Funds negotiated in COP26 would be essential in covering electrification the deficits associated with cleaner energies, such as decentralized electricity technologies (photovoltaic or wind mini grids). However, previous unsuccessful electrification experiences attempting to provide electrification to 15% of people not connected to the grid or experiencing frequent outages suggest that private funding and administrative decentralization might be appropriate to effectively fill SDG7 gaps and cover capital costs and maintenance costs accumulated in almost 20 years since the last electrification wave.

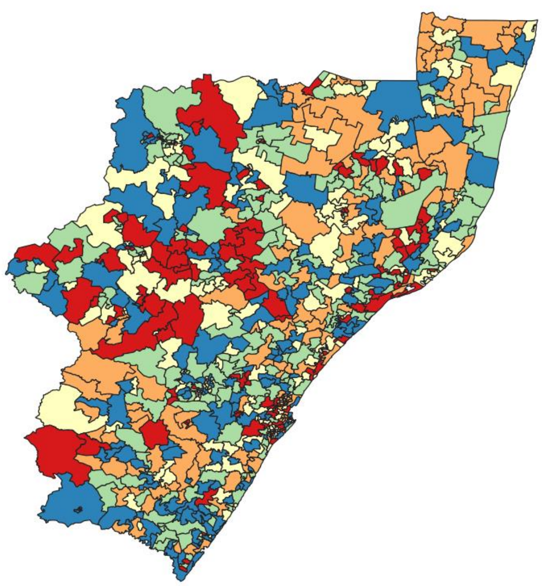
Table 2: Gauteng and KwaZulu-Natal

Provinces

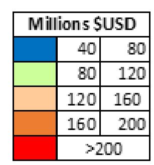

<table>
<tr><th>Gauteng</th><th>Prioritized Cities/Municipalities</th></tr>
<tr><td></td><td>From total resources assigned in table 1, the following cities should receive:

City of Tshwane: 40%
Ekurhuleni: 10%
Emfuleni: 5%
Randfontein: 5%
Midvaal: 20%



Main challenges: 30% of transmission costs is explained by high voltage investments due to mountainous regions in cities located in the outskirts drive costs up. Electric generation deficits explain remaining 70%</td></tr>
<tr><th>KwaZulu-Natal</th><th>Prioritized Municipalities</th></tr>
<tr><td></td><td>From total resources assigned in table 1, the following cities should receive:

Zululand: 32%
uMzinyathi: 20%
uThungulu: 30%
Sisonke: 5%
uThungulu: 13%



Transmission in this region is even more challenging relative to KwaZulu-Natal (50%), for this reason in regions far from the coastal urban centers is critical to invest in off-grid solutions</td></tr>
</table>

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