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Research article

Analysis of power generating plants and substations for increased Uganda's electricity grid access

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Abstract: Uganda is endowed with a number of energy generation sources, however; these sources are spread out or scattered throughout the country. This makes transmission of power from the generating stations expensive. This paper aims at assessing the possibility of reduced cost through increasing substations instead of electricity generation plants through use of Geo pandas and spatial informatics techniques. Power substation data that included coordinates and power ratings, data for Uganda districts, major roads and towns together with population were imported in the jupyter notebook using python and plotting was done to generate a map of power stations in Uganda. The power generating plants, substation, district and population stored data in jupter notebook was retrieved and visualised in GIS where buffering was done in order to determine the area covered by the substations. The point layer of current power substations and plants was buffered at a defined radius to get the current unserved area scenario map for Uganda. As a result of this preliminary work, specific areas were targeted for investment and optimized supply systems was established, which included proposed new power substations. Four power substations were proposed to serve areas without access to the grid and a map showing new sited power stations in unserved areas (densely populated) was generated. Net present worth method was used in the economic analysis to determine whether it makes economic sense in extending transmission lines to serve places without access to electricity vis a vis constructing more power plants. It was observed that extending the grid to selected substations was relatively cheaper as compared to constructing power plants since the economic analysis showed a positive net present worth of USD 63.6 million. Since Uganda has surplus electricity generated, it is better to invest in the transmission lines to serve areas without electricity.

Keywords: transmission; geographical information system (GIS); global positioning system (GPS); grid; geopandas

1. Introduction

In developing countries, electric power is the main engine for the overall economic growth and socio-economic prosperity. The level of electrification in sub-Saharan Africa is low, with less than 10 percent of the rural households having access to electricity [1]. However, weak transmission infrastructure is one of the main culprits in hindering the overall development in these countries and also a cause of societal inequality. Geographical Information Systems and Spatial Informatics Techniques have come as the boon to solve many problems in the Electric power system where demographical and geographical spread was the root cause of insuficient grid extension infrastructure [2]. In a primary transmission network planning problem, the determination of total number, size and location of new substations is among one of the important tasks of planners who are responsible for supplying the loads securely, keeping the medium voltage level in defined limits thus minimizing losses [3].

Uganda is endowered with a number of energy sources, however; these sources are spread out or scattered throughout the country. This makes transmission of power from the generating stations expensive. Most of the parts of the country are not connected to the grid and knowing tapping points (substations) in the country will ease the process of distributing electricity to rural areas that are currently not connected to the grid. In order to construct new transmission lines, different paths might exist. The different paths need to be evaluated in order to find solution that maximizes the benefit [4].

Uganda has tried to construct hydro power plants so as to have enough power to be utilized by the growing population. Today there is excess power supplied to the national grid but only 15% of the population are connected to the grid [5]. The question being asked is whether it is logical to have more power producing plants constructed or invest in constructing transmission power lines to serve households which are far away from the national grid.

Electricity is one of the key indicators of development in any country and the government of Uganda through Vision 2040 goals has already put in place the facilitating policy framework, regulatory mechanisms for investing in power generation, transmission and distribution. This power should be made available at the points of demand consistently and effectively and this is made possible through Uganda Electricity Transmission Company Limited (UETCL). During the last few decades, the company has been involved in the development of primary and secondary substations, transmission lines of high and low voltage so as to meet the high demand of power. Over time, the appropriate routes for new substations and transmission lines have been restricted, as a result of the development of rural areas and the growing concern over environmental issues. According to the companys strategic action plans, which can be accessed through the Rural Electrification Strategy and Plan report 2013 the company is targeting 26% rural electrification access by 2022, 51% by 2030 and 100% by 2040. This is in line with the countrys vision 2040 goals. The company will be able to achieve this target by addition of numerous poles, circuits, power lines, and substations. In addition to the 26% target by 2022, the company needs to reduce system losses, increase grid coverage and improve quality power supply by 2030 [6]. load study analysis and load forecasting studies show that there is need to invest in new primary and secondary substations to achieve an accelerated pace of electricity access and service penetration [6]. Knowing the location and suitable places for substations can minimize on cost of constructing a new transmission line hence more people/places connected to the grid.

This research is aimed at comparing the costs involved in constructing power generating plants vis a vis extending transmission lines to serve places without access to electricity. This will help in locating the most economically suitable sites for future substations. The output of this research will be a map showing Ugandas power generating plants and possible suitable places for substations for future expansion of the grid. Since most of the large power plants are located far from load centres such as cities, balancing the need to develop new markets and reduce operational costs is the greatest challenge for todays utility decision markers. Currently, no estimate for uncovered areas in need of electricity in Uganda due to non available supply from the national grid and the body responsible for transmitting the power keeps paying deemed energy fees to the power producers for unconsumed power. Most scholarly articles are encouraging use of both grids connected and off-grid systems, however off-grid systems do not meet the increasing demand over time. Extension of the national grid to unserved areas will enable consumers utilize electricity without fear of overloading the network.

Centralized option of long transmission infrastructure will not be the only option into the future, there are other distributed energy resources, small scale power generation sources located close to where electricity is used provide an alternative to or an enhancement of the traditional centralized electric power grid [7]. Distributed energy resources are another solution and are working in similar jurisdictions as a way to reduce infrastructure costs and network capital investment costs as well as transmission costs. This research is part of a suite of possible solutions to electricity access. Other than the grid extension lowering the overall system costs, it serves as an option for increasing electricity access and equity and also facilitating the technical and economic integration for variable renewable energy. Grid based alternatives have the singular advantage of being able to meet additional loads, particularly linked to industrial sector growth (electricity demands) which normally develop over time [8]. Grid extension is one of the possible ways to smoothen fluctuations and gain access to areas of high variable renewable energy potential.

2. Literature

Generation and transmission are equally important components of the power system. Generation facilities are responsible for producing electric power, and transmission facilities connects generators to load points [9]. Transmission disturbances often affect the distribution system, but distribution disturbances do not typically affect transmission reliability. The redundancy of transmission networks is critical because the effects of transmission disturbances can be much more widespread than the effects of distribution disturbances and this was the basis for studying the transmission network in Uganda.

Power grid modelling was carried out by reference [10] where open and publicly available data were used. Open data in power grid was looked at where grid simulation models and electricity models applications were differentiated. The grid simulation focused on the technical and physical behavior of electric grids and electricity models were used to manage, plan, extend electricity systems, and managing demands as well as electricity trading. The accuracy of the data used is not accurate since the sources are not credible. The researcher however noted that, although some power data was missing, the quality of the data obtained in SciGRID and OSmTGmod was sufficient in transmission modelling. A spatial electricity planning model developed by reference [11] using arcview GIS and spatial electricity planning and costing model guided grid expansion in countries with low pre-existing electricity coverage. The model rapidly estimates costs and compare with different regions and communities. According to reference [12] geographical information system also helps power companies to discover things about their investments and risks allowing the simultaneous assessment of technical, financial, and environmental factors. It plays an important role in decision making and problem solving through mapping the consumers and electrical network assets on a base map which then define the consumers electrical connectivity. In addition to this, it helps with network routing and power component positioning which determines maximum coverage and the optimal path that has the shortest and the fastest distance and minimum cost. Zeyringer et al. (2015) analysed grid extension and stand alone photovoltaic systems for the cost-effective electrification [13]. The author found two alternatives to meet basic demand either through extension of the national grid or through supply with stand-alone systems. The author found out that stand-alone systems are more suitable for rural households with low demands. GIS and cashflow models were used by reference [14] in finding energy solutions in Africa by mapping electrification costs of distributed solar and diesel generation versus grid extension. The resulting mapping application offers support to decide in which regions the communities could be electrified either with the grid or in an isolated mini-grid.

Due to lack of generic open source tools, Roy et al. (2019) realized researchers and analysts often have difficulty in extracting and analyzing large amounts of spatial data from databases [15]. In order to overcome this challenge, Roy et al. (2019) found out the most effective way is to perform the analysis directly in the database, which enable quick retrieval and visualization of spatial data stored in relational databases using python which performs faster and seamless spatial analysis without having to store the data in memory [15]. It embeds geospatial analytics into spatial database and this gives python an edge in handling large data over geographic information system (GIS).

One of the key barriers to accelerating access is the high cost of connections arising, among other things, from the use of outdated, unsuitable, high-cost methods in electricity networks. A second key barrier is the small and dispersed nature of electricity demand, arising from the low density of population and low-income levels, which lead to high average costs of providing electricity service [1]. A review on transmission of grid extension for the integration of variable renewable energies in Europe was done. Schaber et al. (2012) used a model which minimised the overall system costs and the optimal transmission grid extension cost was determined [8]. Regionally resolved power system model was applied based on linear optimization which includes electricity transport between regions and allows to determine necessary grid extension. Concerning research for electricity planning for countries with low electrification rates, Kaundinya et al. (2009) reviewed papers which compared grid connected versus stand-alone energy systems for decentralized power [16]. Most of the articles were applied to isolated cases and generalized approach to assess suitability of stand-alone and grid connected systems at a given location, based on techno-economic-environmental feasibility did not find adequate coverage. Levin et al. (2012) examined the percentage of population for which decentralized systems would be cost-effective solution [17]. Comparison between the cost of centralised generation calculated via a minimum spanning tree and decentralized generation was done.

3. Methods and tools

Power substation data that included coordinates and power ratings was obtained from Electricity regulatory authority [18]. The collected data was imported in the jupyter notebook using python and plotting was done to generate a map of power stations in Uganda. Data for Uganda districts, major roads and towns together with population was collected from Uganda Bureau of Statistics [19].

District shape file for Uganda was taken as the first input to Geopandas. The shape file contains location attributes and the area of all the districts. Database was obtained for currently installed power generating plants and power substations. The collected data was unified using python software. This process involved checking and confirming that the datasets were in the same projection and datum. Re-projection and conversion were done to the data in different formats. The thematic maps of the identified factors and data sets of the study area were developed. These included; Roads, Transmission Power substations, and Towns with corresponding population. The shape file from the database was used to clip the substations together with their attributes and a map of substations in each sub county was generated. A map showing all the power generating power plants and substations in Uganda was produced using Geo-pandas (python).

Currently installed power generating plants and power substations were mapped on the spatial layer of Uganda to create point layer for power plant and substation. Each point representing a power plant and substation was linked to its corresponding database of geographical coordinates and installed megawatt capacity. The power generating plants, substation, district and population stored data in jupter notebook was retrieved and visualised in GIS. The point layer of current power substations and plants was buffered at a defined radius to get the current unserved area scenario map for Uganda. Buffering was done using GIS in order to determine the area covered within a specific location and reference [20] specifies that the area served by a single substation ranges from 0.5 to 500 square miles. [21] also specifies maximum transmission distance of about 300 miles (483 km). The Transmission Power substations were buffered at 30000 meters radius to determine the distance served by the substation. Dissolving management tool was used for generalizing features in buffering used to remove any overlap thus aggregating the features. The buffered substations were then dissolved to form a complete polygon of the served areas in the study area. The remaining area indicated the unserved areas by power stations as indicated in Figure 6. The map was compared with the population growth in the country to establish power demand centers so as to identify suitable places for substations using GIS. The distances between the power stations and substations were estimated using network topology queries in python. Network topology query was also done to find the shortest distance from the demand centres to the nearest power substations for easy grid extension (see Table 2). Places which are highly populated but without access to the grid were considered in the study and possible alternatives for having electricity access was drawn based on population density maps, local grid connection characteristics, target level and quality of energy access, local energy resources availability and technology cost [22].

An economic analysis was carried out to examine the feasibility of investing in construction of new transmission lines versus investing in a new power plant to serve areas/communities without access to national electricity grid using net present worth method see Eq 3.1. This was accomplished by estimating the cost of constructing transmission lines to the new sited power stations in unserved areas and compared with the cost of constructing a relatively cheaper power plant in Uganda and whose source is available and, in this case solar was considered. Usability of the system was defined in terms of future planning and siting of new substations through a comparative economic assessment between installing new power plants and extending transmission lines by adding new substations. Comparing the present value of incurred costs to the stream of attributable benefits, the net present worth will inform the project's viability over its economic life time estimated at 40 years [23].

$$NPW = \sum_{t=1}^{n} \frac{NCF_t)}{(1 + i)^t} - NCF_o \quad (3.1)$$

where NPW is Net present worth

NCF_t is the net cashflow generated at time t

NCF_o is the initial outlay

n is the life of the project

i is annual interest rate

The costs for constructing substations in Uganda were obtained from ministry of energy and mineral development [24]. The deemed energy fees paid annually by Uganda electricity transmission company in compensating electricity generators for supplying excess power to the grid was taken as benefit in the extension of the grid to unserved areas. According to reference [23], USD 19.5 million is paid out as deemed energy fees every year. The annual substation maintenance costs as per Uganda electricity regulation authority averages USD 75,000 [25]. The annual interest rate i.e., the annual central bank rate (CBR) from the Bank of Uganda (BOU) was used in the economic analysis. The CBR was compared with the financing rate (12%) of Uganda Development bank and the average value (10%) was used [26].

4. Results and discussions

The maps showing demand centers (towns) and road network shown in Figures 1 and 2 were plotted using Geopandas. Road network is an important factor in substation distribution. One would easily notice that almost all the Ugandan medium voltage network lines follow the roads. There are two reasons to this; First is that it takes lesser time in acquiring way leaves. It is easier to seek for way leave along road reserve from the body concerned. However, this is inevitable in areas without clear road network or the costs involved especially in hilly areas where the roads meander around the hills. The second reason and more important of the two is to allow access of the network and the substations during installation and incase of maintenance or repair. The materials are heavy and hence the installation is best suited where vehicles purposed to carry them can efficiently travel along. Towns are referred to as demand centers in this project due to the various businesses set up in their location and towns (with their corresponding population sizes) as illustrated in Figure 1. According to reference [17], Uganda illustrated situations that are less suitable for decentralized electrification due to higher population density. Power is a major infrastructure required for these businesses e.g., shops, hotels, factories, offices etc., hence they have been considered here as a key demand center.

Figure 3 shows power substations in Uganda with the size of the dots on the map showing power the different substations receive from the generating plants. There are 108 substations with different transmission voltage ratings with Kawanda, Kiba, Oriang, Ayago and Karuma (under construction) having 400 kV transmission lines. The majority of the substations in Uganda have 132 kV transmission lines with the least being Lugazi substation with transmission voltage of 66 kV and overhead cables are preferred in transmission of these voltages. Figure 4 shows power generating plants from different parts of Uganda with total power generation capacity by the year 2025 expected to be 3115 MW of which 1223 MW is already installed, 680 MW is under construction and 1213 MW is anticipated to be complete by 2025. Figure 5 indicates the power generating plants in relation to their power producing capacities. Ugandas electricity supply industry is highly dependent on hydro power plants (86%), where large hydro power plants contribute up to 78% of the generation capacity and the small hydro power plants contribute 8%. The generation from the other technologies including plant-by-plant contribution to total generation capacity are summarized in Table 1. As the government is investing in power generation, over 25 industrial parks are planned to be operational by the year 2027 and their estimated power consumption is 1000 MW when fully operational [27]. The excess power generated is anticipated to be 380 MW by the year 2020. Uganda's electricity demand is increasing at a rate of 8.2% annually which translates to 125,000 new customers every year [5]. That means the projected electricity consumption by the year 2025 at a rate of 8.2% increase when all the power plants are fully operational will be 1309 MW from 550 MW in the year 2014 [5] and this will not be able to consume the produced power by then. The investment in transmission is still insufficient and some existing generation capacity cannot be distributed which falls short of the projected consumption [28]. The excess power produced by generators but not consumed will attract a penalty payable by Uganda electricity transmission company limited in form of deemed energy fees [29].

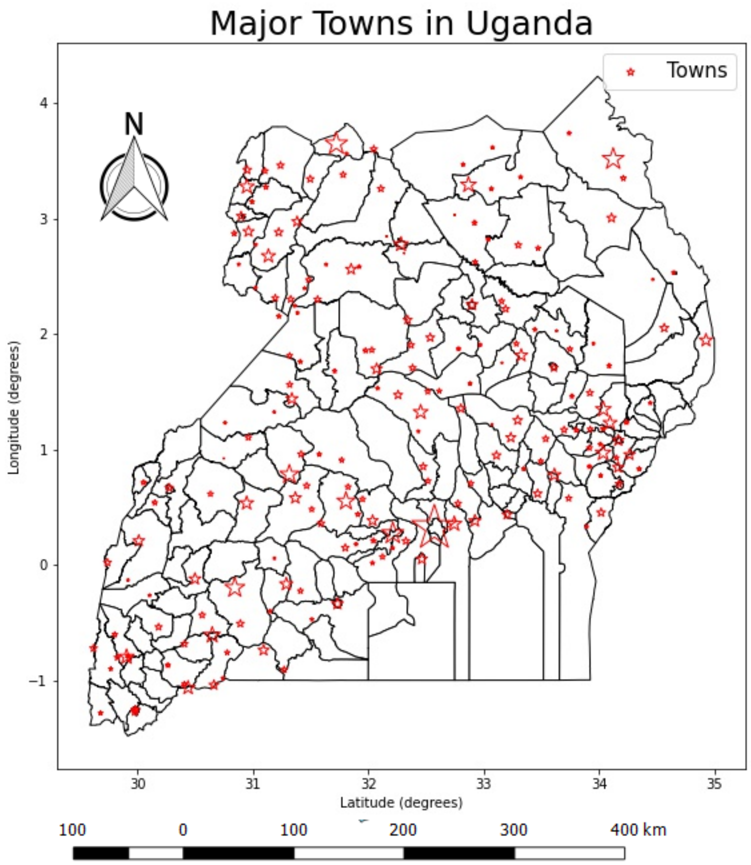

Figure 1. Major towns in Uganda with their corresponding population.

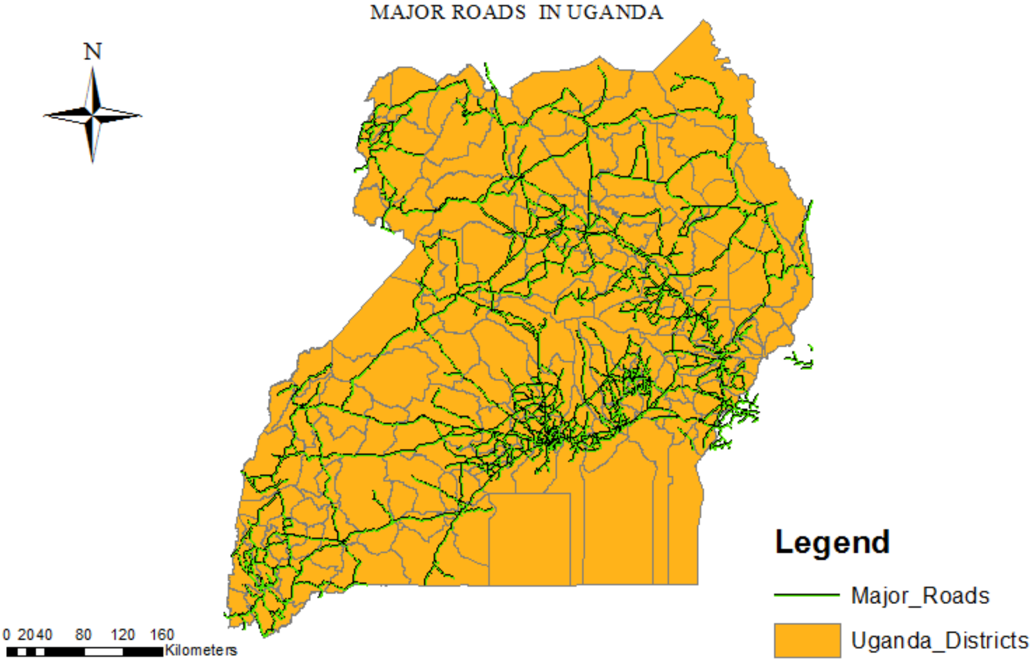

Figure 2. Major roads in Uganda.

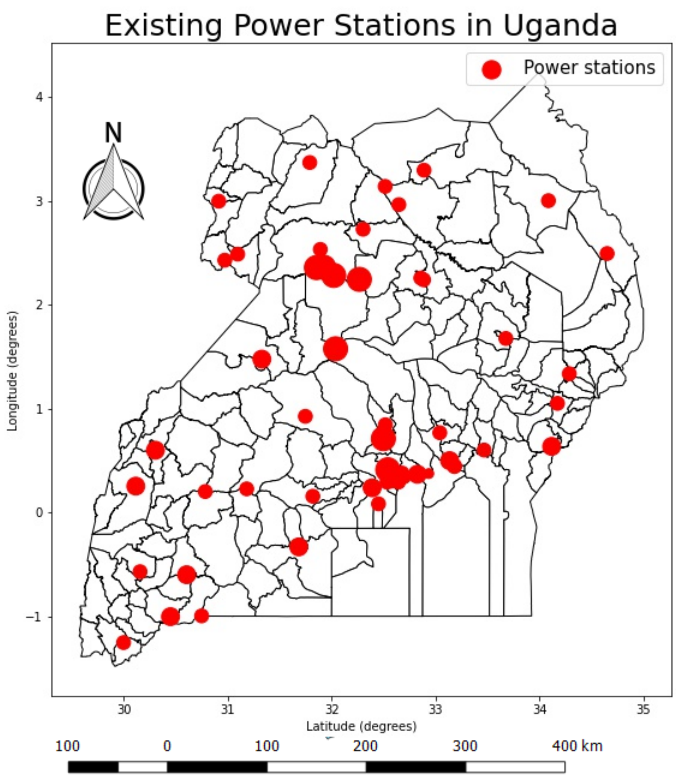

Figure 3. Existing power stations in Uganda.

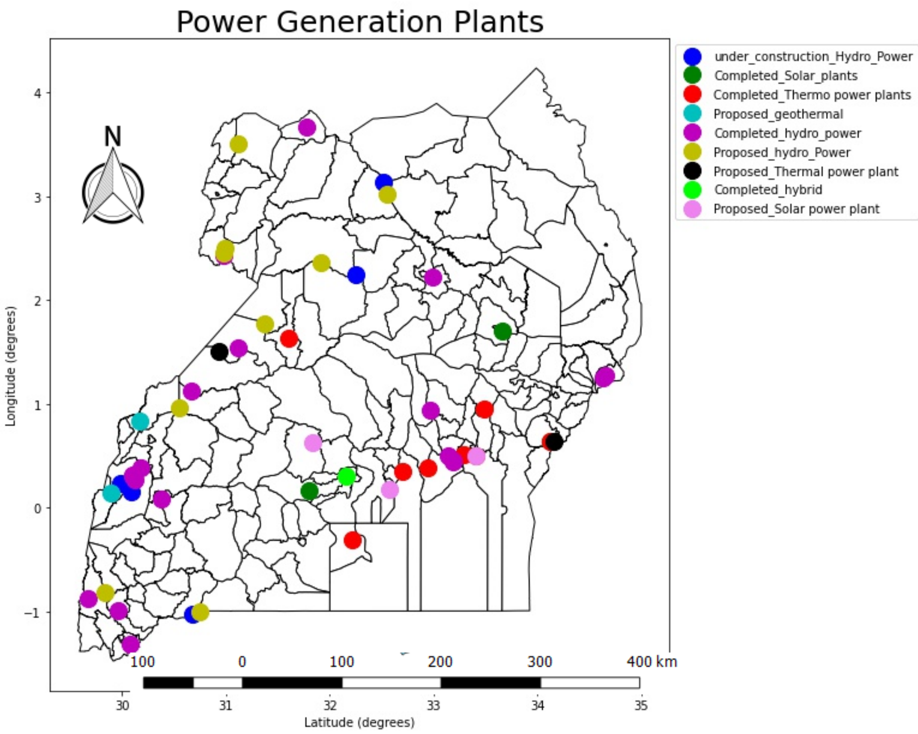

Figure 4. Power generating plants in Uganda.

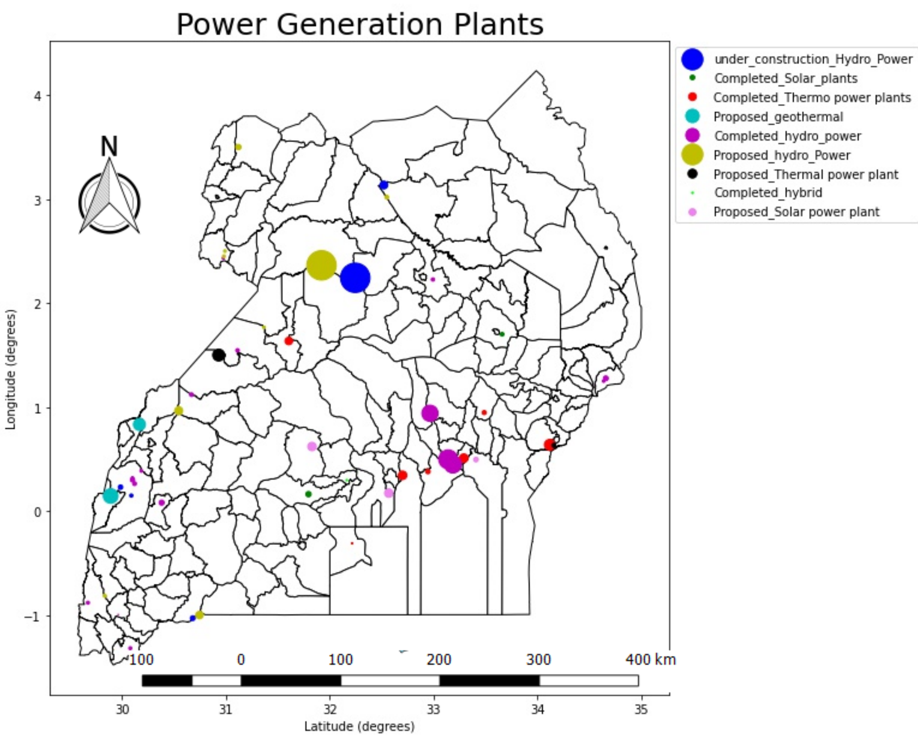

Figure 5. Power generating plants in relation to their capacities.

Table 1. Power plants in Uganda.

Power stations	Capacity (MW)
Completed	
Hydroelectric power station	929.8005
Thermal power station	251.1
Solar power station	40
Hybrid power station	1.6
Under construction	
Hydroelectric power station	679.6
Proposed	
Geothermal power station	250
Solar power station	115
Thermal power station	112
Hydro power	735.96
Total	3115.0605

According to Powers technical standards, a substation is supposed to serve a customer farthest at 30000 meters from its position. For the purpose of this project, the area each substation can serve was determined to be a circle 30000 meters radius. Hence, each existing substation was buffered at 30000 meters as illustrated in Figure 6.

Figure 6 shows the buffer zones that were all dissolved to create total area covered by the existing power substations. Having identified the potential sites, it was necessary to overlay these sites with the factors that had been considered during this project, especially the demand centers. This stage serves to compare how efficient these new sites are to meeting the need of connecting these demand centers. Comparison was done between the potential sites and the initial unserved areas and it was evident that not all unserved areas have the potential of installing additional transformers. This is because some areas are covered by water bodies. Figure 7 shows what remained after buffering power substations which are the uncovered areas and these would then be overlaid for analysis in planning and distributing substations in these areas. Key factors referred to as demand centers were described as centers requiring electricity connection. An overlay of these centers was done with potential sites for new substations. It is evident from the map that four new substations were located during the study in the unserved areas. Computing the buffer of the geographic location as a polygon according to reference [30] would make more sense and using a containment query between polygons helps in getting the areas that are not served by the grid.

The cost of constructing a transmission line for the selected substations Table 2 was estimated using the optimum distances for the new power substations created from GIS and an average cost value USD $333,129 per kilometer for 132 kV [31]. These costs were compared with those of constructing solar, hydro, thermal power plants as shown in Table 3. The economic analysis shows a positive net present worth of USD 63.6 million after service life of 40 years as indicated in Table 4 implying investing in extending the grid to unserved areas is worthwhile. Since all the power that is produced will be utilized by the population, deemed energy costs incurred by Uganda electricity transmission company limited will be reduced. Though literature indicates off-grid systems can make an important contribution in areas with low demand and high connection costs [13], from the estimates, it was observed that extending the grid to selected substations was relatively cheaper as compared to constructing power plants and since Uganda has surplus electricity, it is better to invest in the extension of transmission lines. Parshall et al. (2009) also found out that under most geographic conditions, extension of the national grid is less costly than off-grid options [11]. It is also observed that solar power plant is relatively cheaper as compared to the rest of power plants. In this analysis solar was compared with transmission extension in the study because it is not only cheap but also readily available in every part of Uganda. However, for most private solar power generating companies in sub-Saharan Africa their costs of generation vary between US $0.3 and 0.7 per kWh which is always three times higher than buying the electricity from the national grid [32]. In other words, they sell electricity expensively to the end users.

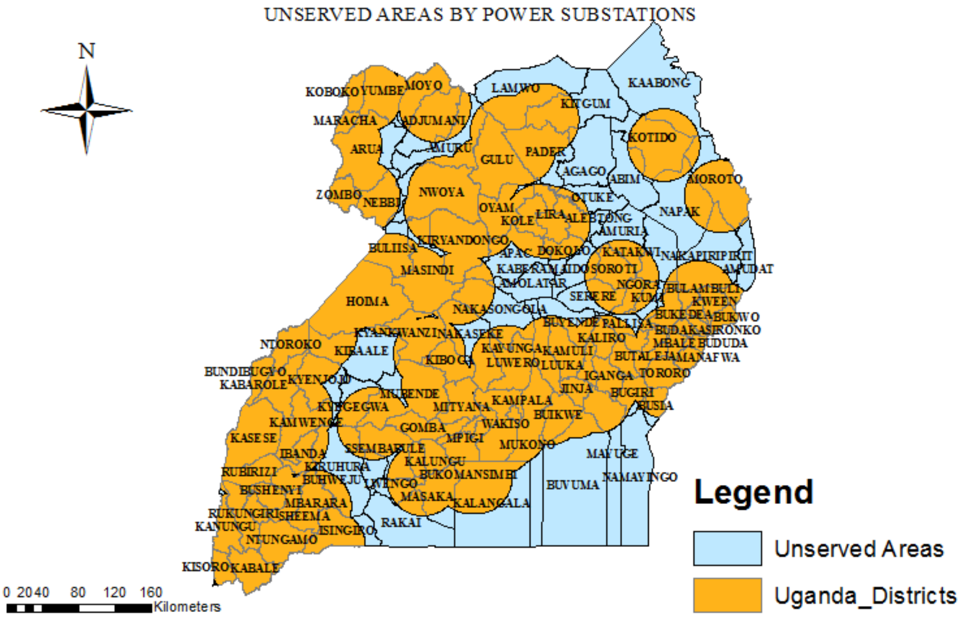

Figure 6. Unserved areas by power stations.

Table 2. Cost of constructing new transmission line to unserved areas.

Power Substation	Nearest Power Substation	Distance between(km)	Unit Price (132Kv) ($)	Total Cost ($)
1	Kotido	81.24	333,129	2,031,000
2	Kitgum	71.31	333,129	1,782,750
3	Masaka West	47.68	333,129	1,192,000
4	Nsongenzi	58.48	333,129	1,462,000

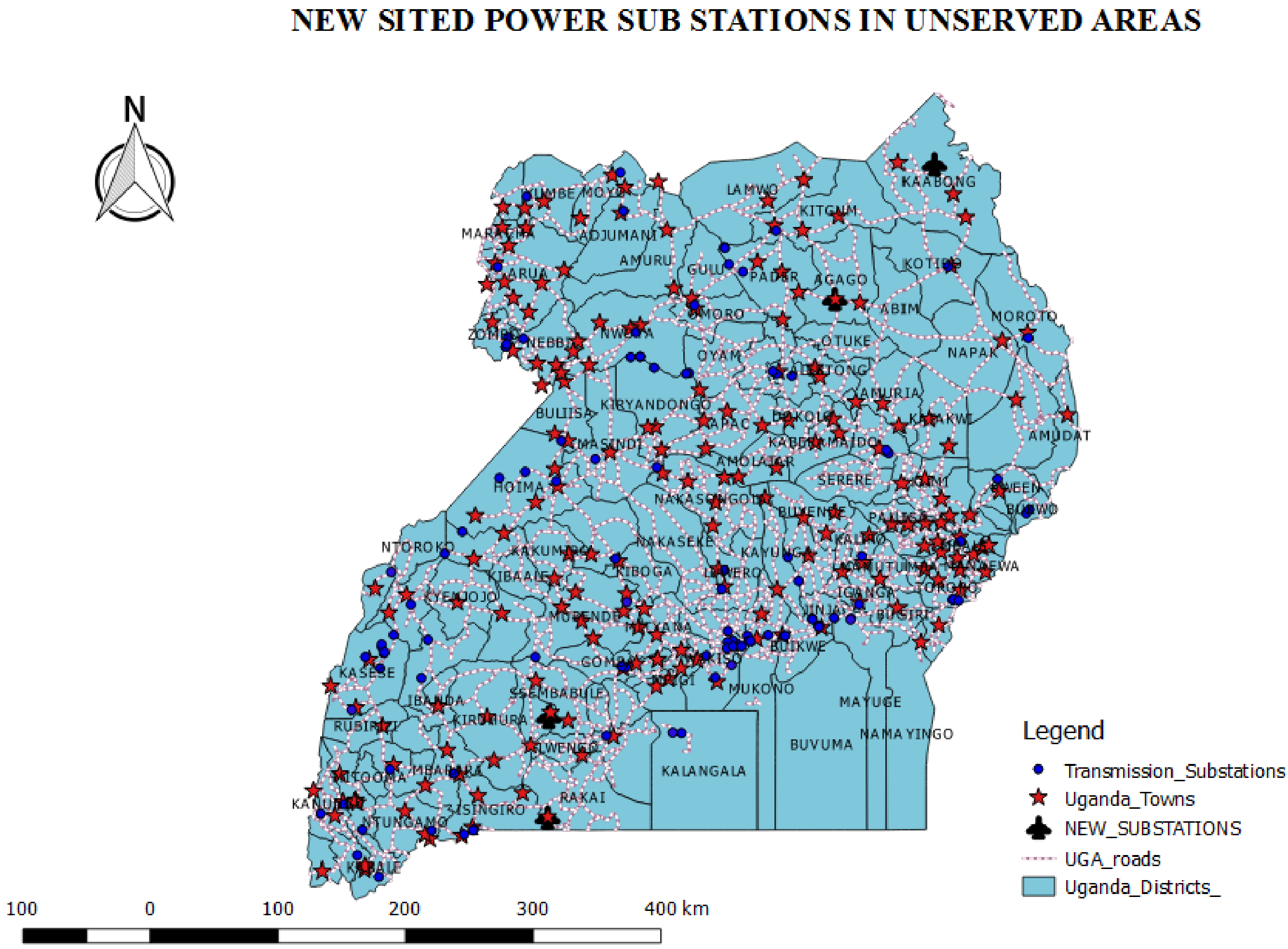

Figure 7. New sited power stations in unserved areas.

Table 3. Power generating plants in Uganda.

Sn	Power generating plants	Total power generated (MW)	Cost of construction ($)
1	Karuma Hydropower	600	1.7 billion
2	Nyagak III hydropower	5.5	19.39 million
3	Isimba hydropower	183	567.7 million
4	Kiira hydropower	250	862 million
5	Bujagali hydropower	255	900 million
6	Soroti solar power	10	19 million
7	Tororo solar power	10	19.6 million

Table 4. Cashflow for extending the grid to unserved areas.

Initial cost (USD)	126,467,750
Annual maintenance costs (USD)	75,000
Deemed energy fees (USD)	19,512,000
Life (years)	40
Interest rate (%)	10
NPW	63,607,659

5. Conclusions

The power generation capacity by 2025 after all the proposed power plants have been installed will be 3115 MW while the projected electricity consumption by the year 2025 will be 1309 MW. It implies that they will be a suplus in generation of 1806 MW. The assessment done in this research shows that costs will be minimized if transmission lines are extended to unserved areas instead of increasing power generation substations as the net present worth of USD 63.6 million showed that extending the grid to the unserved areas was worthwhile. The extension could be done from the nearest substation or generation plant to the new served area for a proposed substation.

Conflict of interests

The authors declare no conflict of interest.

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References

1. Ralph K, Jabesh T, Ian D, et al. (2006) Sub-saharan Africa: Introducing low-cost methods in electricity distribution networks. *World Bank Group.* Available from: `http://documents.worldbank.org/curated/en/333511468204868864/Sub-Saharan-Africa-introducing-low-cost-methods-in-electricity-distribution-networks`.
2. Rezaei N, Nayeripour M, Roosta A, et al. (2009) Role of GIS in distribution power systems. *Int J Electr Comput Eng 3*. Available from: `http://doi.org/10.5281/zenodo.1082103`.
3. Duan DL, Wu XY, Deng HZ (2011) Reliability evaluation in substations considering operating conditions and failure modes. *IEEE Trans Power Delivery* 27: 309316.
4. Meeus L, Nilshenrik VDF, Azevedo I, et al. (2013) Cost benefit analysis in the context of the energy infrastructure package. *Eur J Med Chem* 40: 113123.

5. Stephane de la Rue du Can, David P, David J, et al. (2017) Energy efficiency roadmap for Uganda, making energy efficiency count. *Executive Summary*. Available from: https://escholarship.org/content/qt7wb7r4dr/qt7wb7r4dr.pdf.

6. Rural electrification strategy and plan, 2013. Available from: https://rea.gov.ng/download/rural-electrification-strategy-implementation-plan-resip/.

7. Johnson DO, Petinrin JO, Oyelekan SF, et al. (2017) Integration of distributed energy resources in smart grid system. *International Conference of Science, Engineering & Environmental Technology* 2: 3847.

8. Schaber K, Steinke F, Hamacher T (2012) Transmission grid extensions for the integration of variable renewable energies in Europe: Who benefits where?. *Energy Policy* 43: 123135.

9. Lei H, Singh C (2015) Power system reliability evaluation considering cyber-malfunctions in substations. *Electr Power Syst Res* 129: 160169.

10. Medjroubi W, Muller UP, Scharf M, et al. (2017) Open data in power grid modelling: New approaches towards transparent grid models. *Energy* 3: 1421.

11. Parshall L, Pillai D, Mohan S, et al. (2009) National electricity planning in settings with low pre-existing grid coverage: Development of a spatial model and case study of Kenya. *Energy Policy* 37: 23952410.

12. Javid T (2016) Geographic information system for the smart grid. *Advances in Environmental Engineering and Green Technologies* 344362. Available from: https://www.igi-global.com/gateway/chapter/150328.

13. Zeyringer M, Pachauri S, Schmid E, et al. (2015) Analyzing grid extension and stand-alone photovoltaic systems for the cost-effective electrification of Kenya. *Energy Sustainable Develop* 25: 7586.

14. Szabo S, Odis KB, Huld T, et al. (2011) Energy solutions in rural Africa: Mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environ Res Lett* 6: 034002.

15. Roy A, Fouche E, Morales RR, et al. (2019) In-database geospatial analytics using python. *the 2nd ACM SIGSPATIAL International Workshop* 1724. Available from: https://dl.acm.org/doi/10.1145/3356395.3365598.

16. Kaundinya DP, Balachandra P, Ravindranath NH (2009) Grid-connected versus stand-alone energy systems for decentralized powerA review of literature. *Renewable Sustainable Energy* 13: 20412050.

17. Levin T, Thomas VM (2012) Least-cost network evaluation of centralized and decentralized contributions to global electrification. *Energy Policy* 41: 286302.

18. Ssemwogerere E (2019) Ugandas installed energy capacity. electricity regulatory authority (ERA). Available from: https://www.govserv.org/UG/Kampala/436635406392108/Electricity-Regulatory-Authority.

19. UBOS (2019) Uganda bureau of statistics. Available from: https://www.ubos.org/.

20. Edward C (2017) The basics of primary distribution circuits (substation branches, feeders...). *EEP-Elect Eng Portal*. Available from: https://electrical-engineering-portal.com/primary-distribution-circuits.

21. Marshall B (2004) How power grids work. Available from: https://science.howstuffworks.com/environmental/energy/power.htm.

22. Nerini FF, Broad O, Mentis D, et al. (2016) A cost comparison of technology approaches for improving access to electricity services. *Energy* 95: 255265.

23. John M (2016) Uganda hikes electricity rates for unnecessary power, says report. Available from: https://www.esi-africa.com/top-stories/uganda-hikes-electricity-rates-for-unnecessary-power-says-report.

24. Uganda grid expansion and reinforcement project (GERP). *World Bank Group*, 2016. Available from: http://documents.worldbank.org/curated/en/512271467996734100/Uganda-Grid-Expansion-and-Reinforcement-Project.

25. Kasemiire C (2020) ERA cuts transmission costs by more than half. Available from: https://www.monitor.co.ug/Business/Finance/ERA-cuts-transmission-costs-by-more-than-half/688608-5559412-format-xhtml-bdbg6kz/index.html.

26. Bank of Uganda — Home. Available from: https://www.bou.or.ug/bou/bouwebsite/BOU-HOME.

27. Julius W (2019) Ugandas increased electricity generation. Available from: https://www.independent.co.ug/ugandas-increased-electricity-generation.

28. Oscar A, Andrew H, Maria R (2018) Power aerica in Uganda-energy sector overview. Available from: https://www.usaid.gov/powerafrica/uganda.

29. Mbanga J (2020) Govt kicks off search for investors in transmission grid. Available from: https://observer.ug/businessnews/67034-government-kicks-off-search-for-investors-in-transmission-grid.

30. D'Silva JV, Moor FD, Kemme B (2018) AIDA: Abstraction for advanced in-database analytics. *Proc VLDB Endowment* 11: 14001413.

31. Khandelwal P, Pachori A (2013) Variation of life cycle cost of overhead transmission line and underground transmission cable. *Int J Enhanced Res Sci Technol Eng* 2: 5564.

32. Baurzhan S, Jenkins GP (2017) On-grid solar PV versus diesel electricity generation in sub-saharan Africa: Economics and GHG emissions. *Sustainability* 9: 372.