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CASE STUDY

Electrification planner for Ghana using open-source WebGIS

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Abstract

Energy system planning provides information, such as electrification rate and access, essential to match demand and supply of energy. As countries strive to rapidly grow their economies and increase the living standards of its citizens, energy planning system is essential to keep track of assets, accessibility, adequacy, availability, and distribution of energy resources across locations targeted for development. In Ghana, the Ghana Energy Development and Access Project (GEDAP) was mandated to provide up to 100% electrification rate to the citizens by 2020. While this time has elapsed, public information system showing the spatial distribution and statistical analysis of electrification rate and access in communities and local administrative areas remain scanty. Such decision support system, which can inform energy investment decisions and policy formulation by local and international investors is not readily available, impeding on the Government of Ghana's (GOG) electrification expansion efforts. It also hinders the nation in attaining the United Nation's (UN) Sustainable Development Goal (SDG) 7. Thus, the aim of this study was to develop a decision support system on electrification rate in Ghana. The study used energy access data and open-sourced Geographical Information System (GIS) to map the spatial distribution and provide statistical analysis of electrification rate in the country. The resulting information was connected to a WebGIS that can provide access to query, manipulate, and visualize electrification rate in the counting. The developed system estimated that, presently, Ghana has an electrification rate of 85.16% as of November 2020. This information, and the system in general, will aid decision makers to make swift decision and provide geospatial evidence-based report in achieving 100% electrification rate in the country

Keywords: GIS, Electrification, Energy, WebGIS, SDG 7

Introduction

Electricity access refers to access to stable, relatively simple electricity by a section of people living within a defined geographic space (Mentis *et al.*, 2017). The development of major infrastructure within a country largely depends on energy; therefore, making the resource a major contributor to the economic prosperity of the country. Access to electricity in Sub-Saharan Africa has proven difficult and expensive (Blimpo & Cosgrove-Davies, 2019). In Ghana, significant investments have been made to improve access. Progress has been made in electricity generation capacity from 1,730 Megawatt in 2006 (Kumi, 2017) to 4,310 Megawatt in 2017 (Energy Commission, 2018). The generation sources are hydro (Akosombo, Kpong and Bui Dams), thermal (Takoradi, Sonon Asogli, Cenit, Kpone, and Tema) and solar energy (Nzema, Gomoa Onyandze, and Navrongo). With these developments, about 72% of the population have access to electricity. However, the remaining 28%, mostly in rural areas, still do not have access to electricity It is also estimated that, as of 2012, one-third of households in Ghana did not have electricity (SECO, 2019). This impedes both economic and social activities, as well as hinders developmental efforts especially the many that hinge in electricity.

For Ghana to achieve 100% electrification rate, the government of Ghana and its development partners including World Bank, Swiss Economic Cooperation and African Development Bank introduced the Ghana Energy Development and Access Project (GEDAP) (Energy Commission, 2012). GEDAP aims at increasing Ghana's access to electricity as well as improve efficiencies in the operations of the distribution system. Thus, since 2013, the project has worked toward electrifying and improving electrification across the country. For a new community to be considered for electrification, statistical data accessed through the Ghana Statistical Services (GSS) is analysed. If the population is over 500 inhabitants, the most suitable source of electrification, mainly the National Electricity Grid is used as the generating source. In so doing, several new communities have been electrified. Also, improvement in electrification systems through intensification in already electrified communities have been implemented.

To communicate the status of electrification rate in the country as well as evaluate and monitor the work done by GEDAP, there is the need for a platform to share information about electrification rate in communities.

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That is, it will be useful to develop an interactive and integrated energy planner that can provide the public, government, local and international partners information about the spatial distribution and statistical analysis of electrification rate in communities. Such a system can be accessed by stakeholders in the energy sector to make investment decisions and formulate policies aimed at enhancing the electrification rate in the country. Such a planner will also serve as ready information for the Government of Ghana (GOG) in showcasing commitment to achieving the United Nation's (UN) Sustainable Development Goal (SDG) 7.

Geographical Information System (GIS) has been a reliable tool for integrating, accessing, querying, and displaying information relating to progress in electrification rate. For example, to show the status of energy resources for electricity supply in Ghana, Aboagye *et al* (2021) chose GIS as a platform to integrate the various datasets relating to renewable energy in the country. The system was able to display the various classifications and locations of wind power in the country. Also, to showcase the status of electrification in the country, Kemausuor *et al.* (2012) developed the GIS-based support for implementing policies and plans to increase access to energy services in Ghana (GEAR toolkit). The project provided the Ghana Energy Commission (GEC) with a decision support system to query and view information related to the status of electrification rate in Ghana. Nonetheless, this system was solely developed for the GEC and the public, but other stakeholders did not have access to it. Thus, the system failed to provide the wider public with any information relating to developmental activities in the electrification process in the country. Also, the system contained electrification data prior to 2012 and GEDAP; hence, does not reveal the status of electrification in the country. Most other studies that developed similar tools were based on enterprise GIS platform. Such systems have become difficult to maintain due to the financial involvements. There is thus the need to develop a new open-source electrification planner accessible to the public and stakeholders and updated with current electrification rate in the country.

Thus, the aim of this study was to develop a GIS-based electricity planner to be used as a decision support system for showcasing contemporary electrification rate in Ghana. Extending the capabilities of existing GIS electrification platforms, our system will build a geodatabase and attribute information about electrification rates in Ghana and provide statistical information about communities through charts. More importantly, our system will include a WebGIS, which will provide connection to the geodatabase, as well as user friendly web oriented Graphical User Interface (GUI) which will allow query, manipulation, and display of electrification related information. Such a system can inform the public about developmental activities with respect to electrification rates in the country. Also, it will aid decision makers, policy analysts, international partners, and investors in the energy sector to make policy and investment decisions toward expanding electrification rate in the country. It will also be a ready source of information for Ghana to showcase her successes toward achieving UN SDG goal 7.

Materials and Methods

Study area

Ghana is the study area for the project (Figure 1). Ghana a former British colony gained independence in 1957 and became the first sub-Saharan country to be liberated. Ghana lies between latitudes 4°45'N and 11°N, and longitudes 1°15'E and 3°15'W. The population of Ghana stands at 30.8 million (GSS, 2021).

The electricity production as of 2016 stood at 12.52 billion kWh and consumption was 9.363 billion kWh. Electricity exports also stand at 187 million kWh. Total country electrification stands at 79.3% of the population. Electricity has been provided for 89.8% of the population in urban areas whereas 66.6% in rural areas have access to electricity in 2016 (World Bank, 2017).

Ghana has 16 administrative regions, namely, Greater Accra (where the capital city is located), Volta, Oti, Eastern, Western, Western North, Central, Ashanti, Bono, Bono East, Ahafo, Northern, Savanna, North East, Upper East and Upper West, Regions

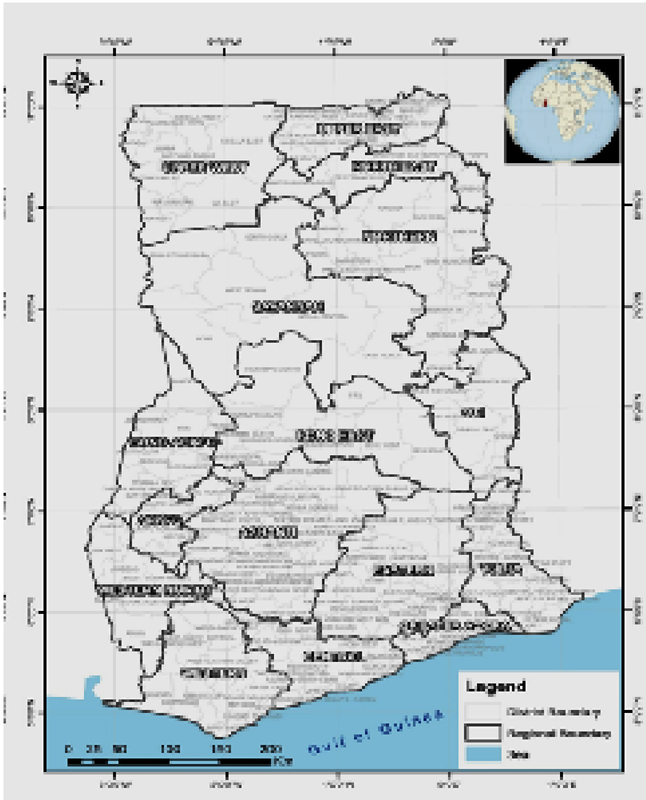

Figure 1 Map of the study area Ghana (CERSGIS, 2019)

Data requirements

The data requirements created the process used to formulate the data needed to accomplish the required purpose. Table 1 shows the datasets required for the web application.

Table 1 Datasets required for the system

Datasets	Attributes	Format	Source
Localities	Electrification Status, Island Status, Population, Community Name, Coordinates, Project Name, Contractor, Year of Electrification	Spreadsheet and Shapefile	GEDAP
Lakes/water bodies	Names	Shapefile	GEDAP
High Tension Lines	Type of Lines	Shapefile	GEDAP
District Boundaries	District Name	Shapefile	CERSGIS
Regional Boundaries	Region Name	Shapefile	CERSGIS
Open Street Map base map		PNG	Open Street Map
Google Earth base map		PNG	Google Earth
Visible Infrared Imaging Radiometer Suite base map		PNG	NASA's Global Imagery Browse Services (Google Earth Engine)

Framework and tools for developing the GIS application

For the purpose of the study, the Waterfall approach (Akinsola *et al* 2020) to software development was used. This approach was adopted because of the known scope of the study as well as the ability to measure progress with development. The Geographic Information Systems (GIS) workflow procedures was designed comprehensively and more carefully, based upon a more complete understanding of the required deliverable.

The WebGIS tools employed in this project serves multiple purposes. It includes tools employed that enable analysis and assessments of data from a geospatial perspective. The energy rate, in a specific area, can be considered in an interactive way. The WebGIS tools make displaying results in meaningful ways, generating reports and charts and rendering the information on a map for a more visceral geospatial feel.

Software development life cycle (SLDC)

The SLDC is a framework adopted for the development of computer software applications (Figure 2). It consists of a detailed plan describing the process of developing, maintaining, replacing, and enhancing the application. The SLDC has five stages that provide a broader framework for the development of the system. The required stages are Planning, designing, development, testing and deployment.

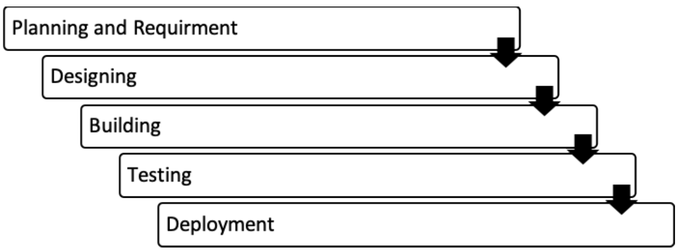

Figure 2 Software Development Life Cycle Diagram (Akinsola *et al,* 2020)

The planning stage requirements can be defined as the input, workflow and outputs expected to be exhibited by the system. Requirement and planning are a crucial stage in all systems development, and if poorly done, can result in the failure of a system or a project. Questions defined as part of this study include: Who are the main users of the system? How will the system be used? What will be the input for the system? What results are expected from the system? To get answers to these questions, there was a peer-to-peer interaction with GIS personnel of GEDAP.

In the designing and development stage, the primary users of the system will be GEDAP and Ministry of Energy. However, some elements of the GIS application will be available to the entire public for viewing. The electrification value of the country at national, regional and district level computed as follows: Electrification Access rate = (Σ Population having access to electricity / Σ of Total Population) X 100% (IEA, 2016). The system is supposed to do these calculations anytime there is an update on the data. These results should be in both map and tabular format.

In the testing and deployment, a unit testing was done on all the functions that were implemented to ensure that syntax, executions and especially logic errors were prevented. The test process was useful in optimizing most of the codes for better performances. The system was deployed on a Linux server on cloud.

Results

The WebGIS for monitoring of the electrification rate of the country is shown in Figure 3. The web pages are divided into three sections; namely: MAP, REPORT and DATA. The Map page has three panel display, that is, the left, middle and right panels as shown in Figure 3.

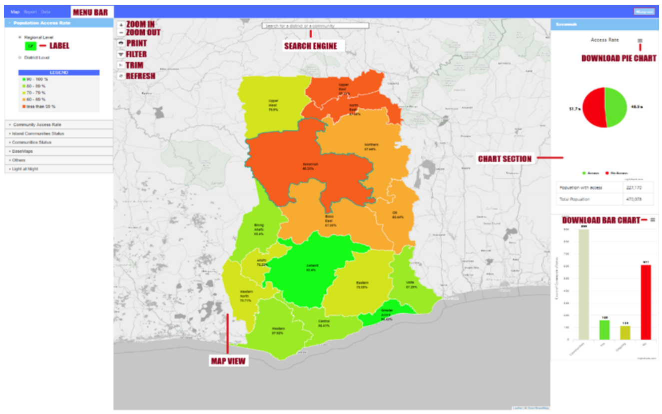

Figure 3 Map Interface of the electrification web application

The left panel contains the layer for each of the data in the system (Figure 4). It controls the visibility toggling of the features on the middle panel. Layers available on the left panel are the electrifications access rate at the regional and district level, islands, and community's status (access to electricity or not, ongoing), base maps and satellite images of the earth at night. Each feature comes with a legend that explains the colour codes used on the map. Some layers also have the label button to toggle the values of that feature on the map in Figure 5.

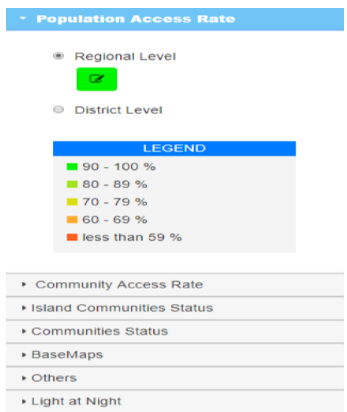

Figure 4 Overview of the left panel with map layers

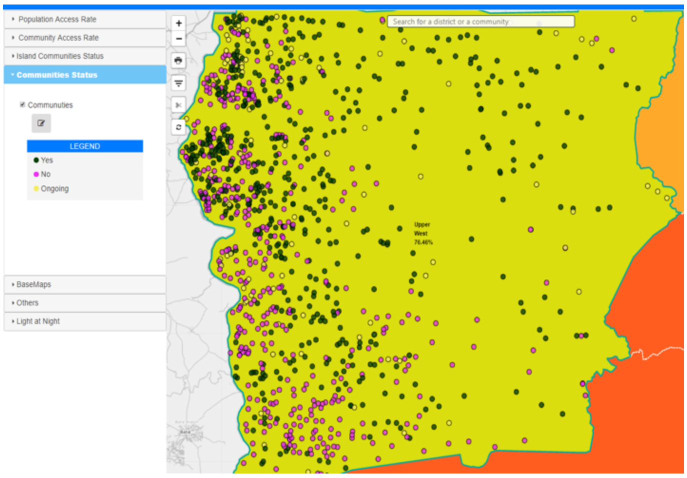

Figure 5 Toggling on the community layer to display on the map

The middle panel, shown in Figure 6, displays the features from the geospatial database as a map. It displays the new sixteen (16) regions, and two hundred and sixteen (216) districts of Ghana and their respective electrification rates map at regional (Figure 6) and district levels (Figure 7). It also displays the various communities and islands with their electricity status. It encompasses different base maps to suit the interest of the user. The middle panel l is an interactive map; therefore, a user can click on a region or district of interest to zoom to the feature. It has tools as zoom in, zoom out, filter, trim, print, refresh and quick search that makes the map interactive.

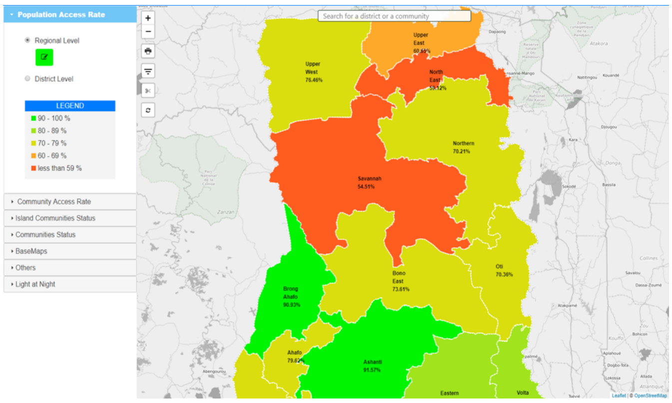

Figure 6 Overview of some regional access rate with labels

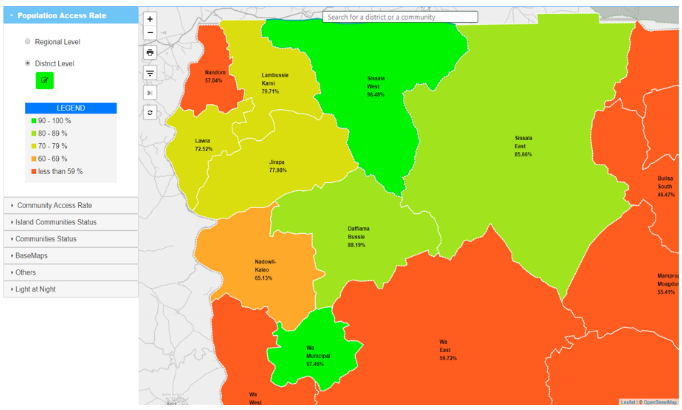

Figure 7 Overview map of some districts access rate with labels

The query panel has two sections, the filter, and the result section. The filter section allows users to filter the community data on the map based on the criteria value. These fields are the island, the electricity status, and population. Rather than having all fields at your display, one can filter a field of interest and query the results. The query field allows users to select a value of interest while the results fields allow users to view query results. At the result section, there is a download button for exporting data into Comma Separated Value (CSV) format. Clicking on a record in the results sections highlights and zooms to the location of the record on the map window. To filter records for a region or district of interest, select the region or district feature on the map and apply the query. Figure 8 and Figure 9 show how the Query panel works to filter data either at the region level and district level.

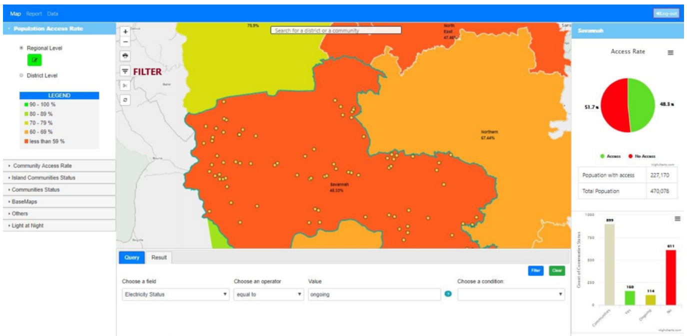

Figure 8 Query of records from the system using the query section

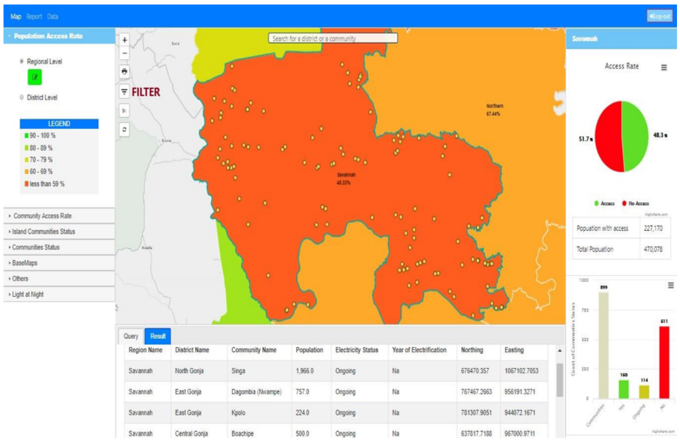

Figure 9 Display of results from the query sections on the map

The right panel contains a summary of the data in pie, bar chart and table format. The pie chart in Figure 10 gives a summary of electrifications rates while the bar chart in Figure 11 count the number of communities based on its electricity status and the table in Figure 10 shows the population that has access to electricity and the total population-based at the national level. The calculated summary at the right panel responds with the region and district layer when its feature is clicked on the map. Figures 12 and 13 show the electrification rate, population and the community count based on electricity status at district level (Volta). The chart results can be exported to PNG, PDF format.

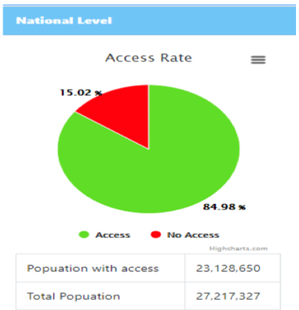

Figure 10 Summary of population data at national level

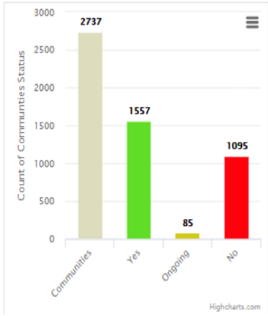

Figure 11 Community status at national level

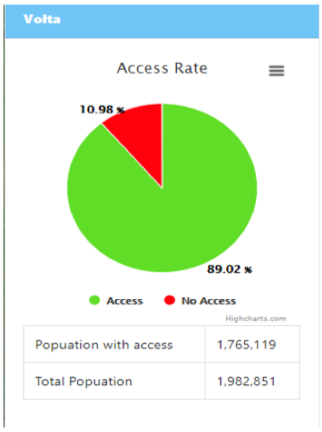

Figure 12 Summary population data at a district level

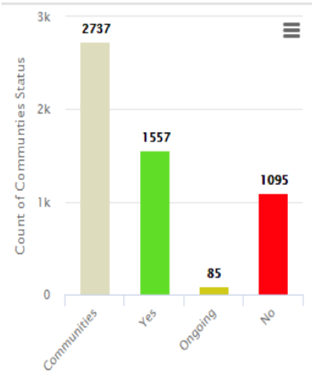

Figure 13 Community status at national level

Discussion

The results of this study have shown the capabilities of our system can provide reliable information regarding electrification in Ghana. Our system displays the current electrification rate for communities, districts, and regions across the country. It identifies Island communities that cannot be readily connected to the national grid, communities eligible for electrification, and provide the necessary projection information for attaining planned electrification rate. The web GIS aspect makes the system user friendly and accessible to all audience.

Our study developed an interactive and integrated GIS-based electrification planner that shows the status of electrification rate in Ghana. This is an advancement of existing electrification planners in the country. For example, the GEAR toolkit (Kemausuor *et al*, 2012), which is also electrification planner, is static, and does not allow introduction of updated data. This makes the information in the GEAR obsolete since it contains energy information collected prior 2012. The GEAR toolkit is also desktop bound, rendering its users to only proprietary stakeholders. On the other hand, our system is scaler with interactive maps and can be updated as and when data becomes available. Also, the web aspect means that the system can reach the worldwide audience and variety of stakeholders. Individuals and companies can query, manipulate, and retrieve information from the system for investments and policy decision purposes. Our system is similar to energy software tools such as the 'Sustainable Rural Energy Decision Support System (SURE DSS) (Cherni *et al*, 2007) being used to monitor rural electrification rate in the UK.

The current 85% electrification rate shows that the nation has moved up by 13% in electrification within a 7-year period, with annual rate of 1.85%. That is, there has been an increase in accessibility to electricity by the populace, which can enhance and improve socio-economic activities. Domestically, people will have more access to electricity for lighting, cooling, and refrigeration, and for operating appliances, computers, and electronics enterprises thereby enhancing their daily lives. Industrially, across the services, manufacturing and mining industries will have greater access to electricity to improve production, distribution, research, and development (Ateba *et al.*, 2019). As national development hinges on improvement in domestic wellbeing and industrial expansions, the current expansion in electrification rate sets Ghana on the right developmental trajectories.

The 85% electrification rates also set Ghana ahead of all West African countries in electricity accessibility rate, giving the nation a leverage in trade in electricity among her neighbours. That is, the nation holds potentials to lower her energy prices, mitigate against power shocks, relieve shortages, facilitate decarbonization and provide incentives for market extension (Pollitt and Mckenna, 2014; Antweiler, 2016), compared to the other 15 nations in the sub-region which has lower electrification rate. This makes Ghana a focus for regional and international investments in comparison to her neighbours. It also sets the nation on a better path to adhering to and attaining international goals set to mitigate environmental problems such climate change.

Further, our electrification planner can be used for near-term and long-term planning of electrification in the country. The ability to identify Island communities which may not be economical to electrify using the national grid provides GEDAP and other stakeholders the prior information to consider other sources of energy such as solar or wind for electrification. The capacity of our system to determine communities eligible for near-term electrification due to their current population and road access makes the system the right tool for near-term electrification planning. These capabilities allow our planner to be effective in projecting and attaining a particular electrification target as it can help to determine which communities/areas can provide an estimated electrification value. Such information is useful for the government to make informed decisions toward expansion of electricity in the country. The information is also particularly useful for other stakeholders and international partners to make investments decisions in the energy sector of the country.

Finally, this system as well as the information that it provides on electrification rate in the country is proof of the successes achieved by the GEDAP. The project has been able to significantly expand electrification in the country. However, the 85% electrification rate is below the mandated 100% planned to be achieved by 2020.

Conclusions

This study demonstrates the potential open-source GIS solutions in determining the rate of electricity access in any country. The developed WebGIS application is dynamic and therefore the rate is expected to change anytime electrification projects are completed and the data fed into the application.

The study recommends the application for use by decision makers and stakeholders in identifying communities that meet the criteria of electrification, which will contribute to about 4% increment in the national electrification rate and reach the 100% electrification rate for SDG 7. The open-source web-based GIS application produced in this study can be easily replicated in other institutions anywhere in Ghana that seeks a faster, efficient, accurate and open access GIS solution to utility access monitoring at very minimized cost.

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Conflict of Interest Declaration

The authors have no affiliation with any organisation with a direct or indirect financial interest in the subject matter discussed in the manuscript.

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