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# Visualizing National Electrification Scenarios for Sub-Saharan African Countries

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**Abstract:** Some 630 million people representing two-thirds of all Africans have no access to electricity, which is identified as a key barrier towards further development. Three main electrification options are considered within our work: grid extensions, mini-grids and solar home systems (SHS). A methodology is applied to all sub-Saharan African countries to identify in high geospatial resolution which electrification option is appropriate taking into account datasets for night light imagery, population distribution and grid infrastructure. Four different scenarios are considered reflecting grid development and electrification constraints due to low population density. The results clearly indicate a dominating role of SHS for achieving a fast electrification of the not supplied people. The share of supplied people by mini-grids is found to be rather low while grid extension serves a large share of the population. The decisive factors for these distinctions are population density and distance to grid. We applied several scenarios and sensitivities to understand the influence of these key parameters. The highest trade-off happens between SHS and grid extension depending on the selected thresholds. Mini-grid deployments remain in the range of 8 to 21%.

**Keywords:** off-grid; rural electrification; solar home systems; mini-grid; grid extension; geographic information system (GIS); sub-Saharan Africa

## 1. Introduction

In the last decade many interventions, projects and programmes targeting rural electrification in Africa have been initialized by international and national stakeholders. Nevertheless, in sub-Saharan Africa a population greater than 630 million people (two-thirds of all Africans) still lack access to electricity with an overall low electrification rate of 35% [1]. Additionally, the ones already connected to electric power supply are facing high costs and suffer from a poor power supply quality due to frequent power outages [2]. The low quality of supply is hindering economic growth in Africa [3,4] and estimated real GDP losses for the entire continent are at least 2% per year [5]. The absence of electricity affects the development opportunities of the African population, especially in rural areas and negatively affects healthcare supply and education. Despite successes in certain large countries such as South Africa and Ghana, the number of people without access to electricity actually rose in 37 countries in the region since the year 2000 [6]. This highlights the urgent need for developing electricity access solutions for the African continent especially as it is expected that population growth, urbanisation and digitalisation will rapidly increase energy demands [2]. Such interventions are in line with the Sustainable Development Goals (SDG) announced by the United Nations (UN) to target several development goals until 2030 with access to sustainable energy for all (Goal #7) being one of them.

Achieving SDG 7 through rural electrification in sub-Saharan Africa is a special challenge due to the large distances, a lack of capital, data paucity and a shortage of expertise [7]. The traditional approach of extending the existing grid is often not economically feasible, especially in remote rural areas with low population densities as the required investments cannot be amortized within a reasonable time frame. Additionally, many sub-Saharan African countries face a low grid quality with frequent power outages of several hours due to poor maintenance and overload of the system [7]. This concludes that the conventional approach of centralized electrification cannot solely solve the energy access challenge in sub-Saharan Africa.

In contrast to centralized approaches, decentralized approaches prove to be increasingly interesting especially with higher maturity and decreased costs of PV technologies and batteries [8]. For single households solar home systems (SHS) represent an easy way of supplying electricity to serve basic needs such as lighting, radio, digital music or mobile phone charging [9]. PV hybrid mini-grids even allow 24/7 electricity supply for communities or remote industries [10–12]. Thus, with these technologies a decentralized electrification approach seems possible in a cost-effective and environmental friendly way. Providing electricity by off-grid renewable energy technologies could allow for a leapfrogging of grid based electrification similar to the development in the telecommunication sector [13].

Despite of the opportunity that decentralized approaches such as SHS and mini-grids display for accelerating rural electrification, a big knowledge gap remains exactly where such approaches should be favoured over centralized ones which is grid extension. We contribute to overcome this knowledge gap by conducting a spatial feasibility assessment of the aforementioned electrification options; namely they are SHS, mini-grids and grid extension for different scenarios. Key parameters for assessing the feasibility are the existing and planned grid infrastructure and population density. The results enable policy makers, investors, and other stakeholders of the electrification sector to allocate their resources accordingly and to set the right framework conditions for certain electrification options. In addition this geospatial analysis allows understanding the total numbers to reach 100% electrification rates in sub-Saharan countries for the different electrification options. Therefore the results are of international interest. In addition, rural communities can better understand the local feasibility of electrification options and take action accordingly. Finally we provide comparable insights for all sub-Saharan African countries based on a geospatial analysis.

The presented paper visualizes national electrification pathways for sub-Saharan African countries. Thereby it contributes to the discussion whether centralized or decentralized approaches shall be applied for electrifying vast areas of the African continent. The paper is structured in the following way: Section 2 presents the literature review on electrification planning tools. The applied methods and datasets are described in Section 3. The results are provided in both an aggregated and detailed way for all sub-Saharan African countries in Section 4. The results are discussed in Section 5 and, Section 6 concludes the discussion.

## 2. Literature Review

The scientific community agrees that access to electricity is a key prerequisite for enabling economic and social development [14]. The impact of electricity access for development is confirmed by several scientific and applied case studies which revealed significant positive impacts, for example on household income, expenditure, health care, and educational outcomes [15–25]. In particular for grid [26], SHS [27] and mini-grid [28] electrification the beneficial impacts on households with regard to illumination and access to information have been underlined while a direct economic impact remains uncertain for grid [26] and SHS [27] based approaches.

Various electrification strategies from grid extension to decentralized small-scale energy generation have been analysed by Kaundinya et al. [29] and Bertheau et al. [30]. The two studies stress the complexity of the available options, which require sophisticated decision support tools to identify the optimal electrification solution. Furthermore, it is crucial to understand the socio-technical transformation that is enabled by electrification processes and renewable energies [16,31]. Therefore, decision support systems are needed for practitioners [32], especially since new stakeholders such as private investors are looking for innovative business models that match the novel opportunities in developing countries [33,34].

The complexity of electrification solutions requires advanced planning software tools and instruments to identify least-cost electrification options. Several technical planning tools exist for the design of rural electrification projects, each with different strengths and weaknesses. HOMER Energy is a frequently applied planning tool capable of optimizing and simulating hybrid mini-grid systems [35]. Its application has been demonstrated for a number of developing and emerging countries, such as Nigeria [36], Ethiopia [37], and Cameroon [38]. Furthermore, researchers developed similar tools to HOMER, e.g., Ranaboldo et al. [39,40] and Huyskens and Blechinger [41] including additional features, such as a one minute resolution. Nevertheless, these tools enable the investigation of one specific electrification scheme, while neglecting geographic comparisons for infrastructural planning. Such a spatially resolved comparison of electrification schemes (grid extension, off-grid diesel, off-grid PV) was initially introduced by Szabó et al. [42] and improved with hydro-power as a possible electrification scheme [13]. These studies can be considered as path-breaking for electrification planning despite their rudimentary character in important aspects, e.g., grid extension and cost calculation of off-grid systems. A spatial electrification planning tool specific for small hydropower was developed and applied for Müller et al. [43]. Modi et al. [44] introduced another approach (Network Planner) which enables a more detailed spatial planning for electrification concepts of entire regions or countries. One of the most recent approaches for geospatial electrification planning has been elaborated by Mentis et al. [45]: The authors state that successful electrification is based on geospatial questions and challenges and the usage of GIS potentials is not yet fully utilized [46]. Within an applied research project the Reiner Lemoine Institute (RLI) presented a methodology to combine spatial planning for electrification in Nigeria with energy system modelling, based on a detailed demand study [47]. Results for Nigeria show different results for different regions, based on their spatial relations and attributes. Regions with already existing grid dominance are suggested to be electrified rather by grid extension than by decentralized solutions, whereas electrification options in remote regions have higher shares of solar home system and mini-grid solutions. Additionally, inter-linkages between least-cost planning tools and business models for electrification are missing as well as approaches which can provide first guidelines on how a country can improve its respective electrification strategy. Therefore this study adds to the development of electrification planning tools in sub-Saharan Africa by taking into account demographic parameters for the selection of electrification options. Also, comparative analyses between different countries are lacking, since the described approaches are mostly applied to single countries only, notwithstanding that such a comparison can facilitate a better understanding which solutions might suit best for certain countries and regions.

## 3. Materials and Methods

The method applied in this paper pursues a geospatial approach and is based on datasets on population distribution and densities, existing and planned grid infrastructure and night light satellite imagery. Finally an electrification scenario for grid extension, mini-grids, and SHS systems, based on local population distribution and grid extension distance, is visualized for non-electrified regions of sub-Saharan Africa.

### 3.1. Country Selection

Initially the target countries for this study are selected. Due to the focus on electrification the selection was limited to sub-Saharan African countries leaving the North African countries and island states with relatively high overall electrification out. In total 45 countries are considered in this study (detailed information is provided in Figure A1 and Table A1 of the Appendix 7).

### 3.2. Data Collection

For this study an automatable programming routine is developed by applying open source software such as Python (2.7, Python Software Foundation, Beaverton, OR, USA) [48] and QGIS (2.8, QGIS.org, Grüt, Switzerland) [49]. Furthermore only freely available data on population [50], night light emission [51] and transmission grids [52,53] is utilized and processed, as visualised in Figure 1. As a result, the proposed methodology can be easily applied for further regions, adapted or evolved for more detailed studies.

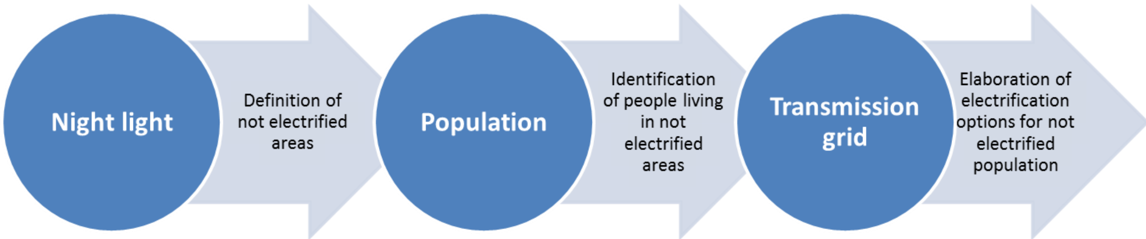


**Figure 1.** Datasets applied in this research for identifying geospatially resolved electrification options.

Night light imagery is applied for distinguishing the African continent in "electrified" and "not electrified" areas which are defined by light emissions respectively the absence of light emissions (step 1 of Figure 2). Based on this analysis a "mask" layer for "not electrified" areas is created. This layer serves for defining the population living with or without electricity when investigating spatial population datasets (step 2 of Figure 2). Finally for the identified population living without power supply electrification options are elaborated based on their vicinity to the grid and population density (step 3 of Figure 2).

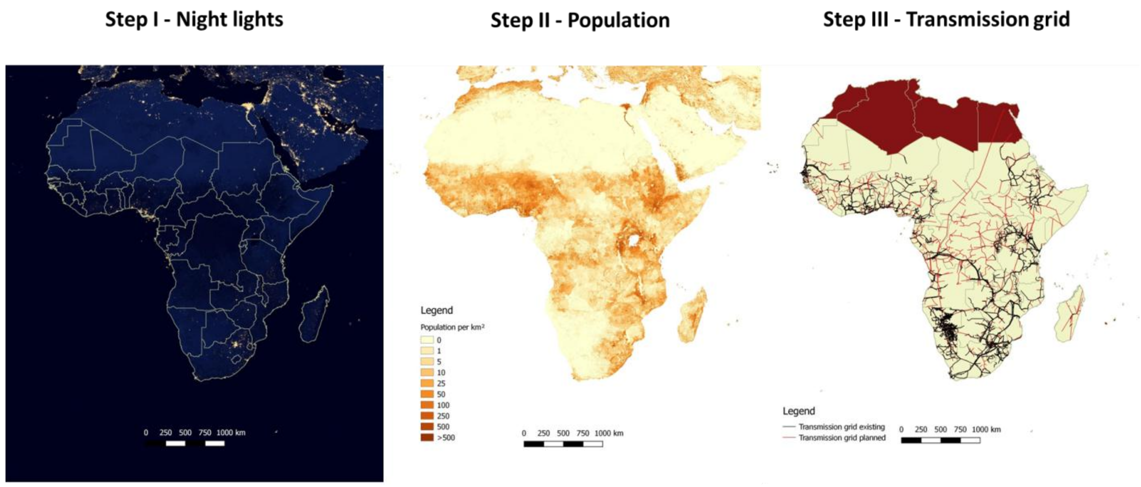


**Figure 2.** Visualised data used for geospatially resolved analyses structured in step I (night lights), step II (population) and step III (transmission grid).

### 3.3. Population

For assessing population numbers the *WorldPop* spatial population datasets was applied as shown in Table 1. This source is a compilation of various datasets based on official population estimate data and census data. Information is provided on a 100 m × 100 m resolution and the applied methodology is further described in [54–56]. Individual raster files per country were obtained from the data source. For the overwhelming part of countries recent data from 2014 or 2015 was applied besides that for Lesotho and Congo (Brazzaville) where the only data available was from 2010.

**Table 1.** Datasets used for analysing the geospatially resolved electrification options.

| Data | Source |
|---|---|
| Population data | [50] |
| Night lights | [51] |
| Transmission grids | [52,53] Further individually researched and processed |

### 3.4. Night Light

Night light satellite imagery provided by NASA is applied for defining areas with light emissions as electrified and areas without light emissions as not electrified. The imagery was recorded by the Suomi National Polar-orbiting Partnership (NNP) satellite over a period of 22 days in 2012. National Aeronautics and Space Administration (NASA) Earth Observatory image by Robert Simmon, using Suomi NPP VIIRS data provided courtesy of Chris Elvidge (NOAA National Geophysical Data Center). Suomi NPP is the result of a partnership between NASA (NASA, Washington DC, USA), NOAA (NOAA, Silver Spring, MD, USA), and the Department of Defense. The methodology is further described in [57].

### 3.5. Transmission Grids

Spatial data on transmission grids was derived from two main sources: The African Development Bank (AfDB) and the United Nations−Department of Economic and Social Affairs (UN-DESA) as shown in Table 1. Both sources provide spatial information on most high voltage transmission lines existing in Africa. Nevertheless for a number of countries no data was available. In such a case grid information was individually researched through approaching national ministries and agencies as well as other relevant sources. In cases of exclusively physical maps on the spatial distribution of transmission grids was provided, the information was digitalized by applying GIS.

### 3.6. Detection of Population and Definition of On- and Off-Grid Regions

Night light information is crucial for defining electrified areas through the occurrence of light emissions. However, the night light data provides no clear or binary indication on the existence of light. Instead the data is structured in a composite of three bands of which only band one is used for further analysis. Only the first band is chosen because all three bands combined did include water reflections on lakes and on certain land cover in uninhabited areas. Higher values in the first band corresponded best with settlement structures where the source is most likely artificial lighting. The values of this band range from 0 to 255 and are reclassified into binary values which are defined by light or no light. For this reclassification a threshold needs to be defined. Therefore a sensitivity analysis was conducted which compared the identified number of people living without access to electricity when applying night light imagery as indicator to values on electrification rates provided by the International Energy Agency (IEA) [58]. Subsequently, a sensitivity analysis was carried out with night light threshold values from 5 to 25. Figure 3 shows the average derivation from IEA energy access rates according to single night light bands aggregated for all 45 sub-Sahara African countries. From values higher than 12 onwards the derivation is very small. Nevertheless as the derivations are higher for single countries we finally applied a single value for each country which was the closest value compared to the values of the IEA. The individual values are disclosed in Table A2.

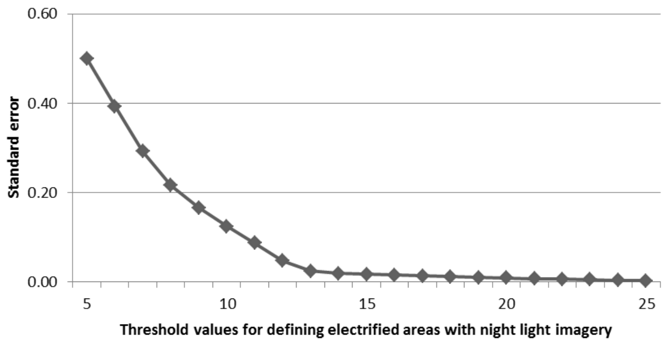


**Figure 3.** Standard error of calculated electrification rates to IEA statistical electrification rates [58] by using different threshold values for sensitivity analysis of night light imagery. Summary for all considered 45 sub-Saharan African countries.

### *3.7. Identifying of Population Living in Reach of Power Transmission Infrastructure*

For assessing the percentage of non-electrified population living near the power transmission infrastructure, the area around the grid is buffered with a buffer radius of 25 km. Previous research used comparable buffer sizes for assessing grid extension scenarios [42]. Followed by that, the accumulated population number within proximity of the grid is calculated. These results clearly show that a high share of the overall population is living near existing grid infrastructure and highlights the importance of "grid densification" approaches.

### *3.8. Recommended Electrification Options for All Non-Electrified Regions*

Based on the previous analysis of electrified and non-electrified population and respective grid infrastructure, electrification options are analysed and defined for all non-electrified regions. Considered options for electrification are grid extension, mini-grids and SHS. Two different scenarios are developed to account for the specifically low population densities near grid infrastructure (Figure 4).

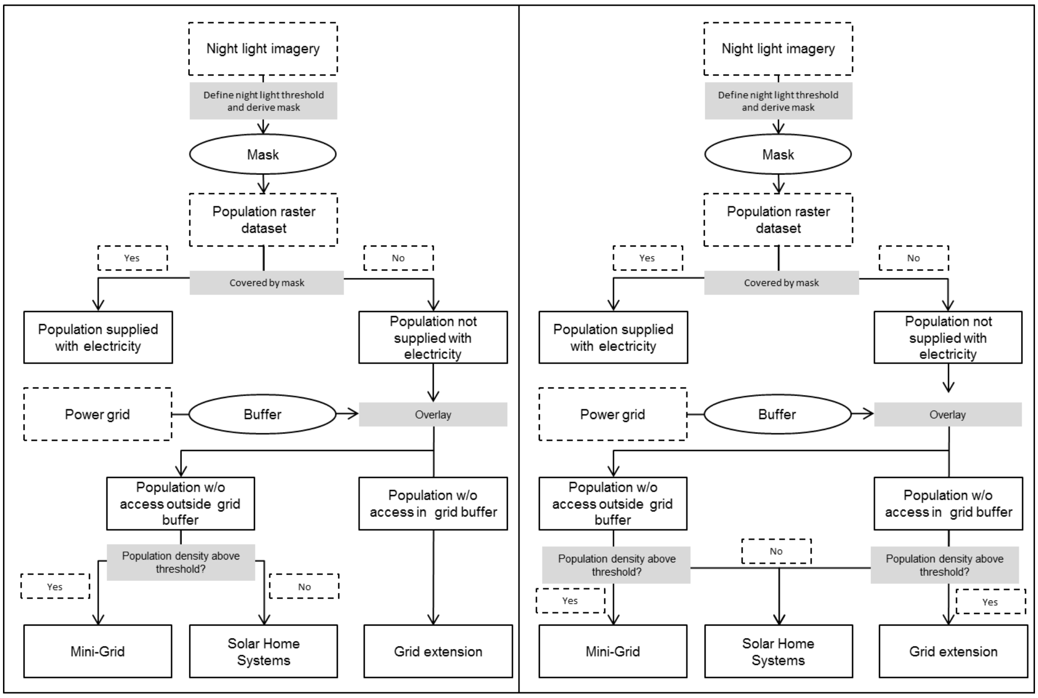


**Figure 4.** Flow chart of appropriate electrification option selection for excluding (**left**) and including (**right**) the population density within the grid buffer.

In the first scenario the assumed optimum electrification path for people within the grid buffer is grid extension. Outside the grid buffer, mini-grids and SHS are assigned as the best options depending on population density (left side of Figure 4). However, some regions within the grid buffers are characterized by low population densities and grid extension is unlikely the best option for these regions. A further reason for that is the necessity for transformer stations to establish a branch duct to connect a new region, even though it has only a low population density. Therefore, a second scenario is developed where SHSs are defined for all locations with population densities under a certain threshold, also within grid buffers (right side of Figure 4). After a visual sensitivity analysis by using satellite imagery, a population threshold value of 400 persons per km$^2$ is chosen, as this enabled the identification of larger villages. Additionally other study found that electrification options other than SHS onwards become cost effective from 100 households per km$^2$ which is comparable to the applied threshold [59].

## 4. Results-Electrification Scenarios

The applied methodology identifies a total population of 332 million living in areas with night light emissions and 620 million in areas without night light emissions. This results in an electrification rate of 35% which is in line with the official statistics provided by the IEA on energy access in sub-Saharan Africa [60].

For the first scenario considering the existing grid infrastructure our results highlight that the extension of grid by 25 km bears the potential for covering 46.9% of the currently unsupplied population (Table 2). Mini-grids are assigned to regions outside the grid extension zone with a population density higher than 400 persons per km$^2$. Although mini-grids have the lowest share of 12.4% they still reflect a potential of more than 76.6 million customers. Finally our projection underlines the importance of solar home systems for electrifying Africa as a population of 252.7 million representing 40.8% of the currently undersupplied shall be equipped with SHS under the applied thresholds.

**Table 2.** Quantification of electrification options depending on excluding (grid-based) and including (SHS-based) the population density within the grid buffer zone based on the existing grid infrastructure.

| Electrification Options | Grid-Based | | | SHS-Based | | |
|---|---|---|---|---|---|---|
| | **SHS** | **Mini-Grid** | **Grid** | **SHS** | **Mini-Grid** | **Grid** |
| Share of not supplied population | 40.8% | 12.4% | 46.8% | 71.3% | 12.4% | 16.3% |
| Absolute population in million | 252.7 | 76.6 | 290.3 | 442.0 | 76.6 | 101.1 |

The relevance of SHS becomes even more emphasised with regard to the SHS based scenario. Here we have assigned areas to SHS supply even in the grid extension area if the population value was lower than the threshold (400 persons per km$^2$). Under this assumption SHS are the leading technology for electrification of sub-Saharan Africa with the potential of delivering electricity to almost three quarter of the not supplied population (Table 2). Results for all sub-Saharan African countries on basis of the already existing grid are depicted in Figures 5 and 6.

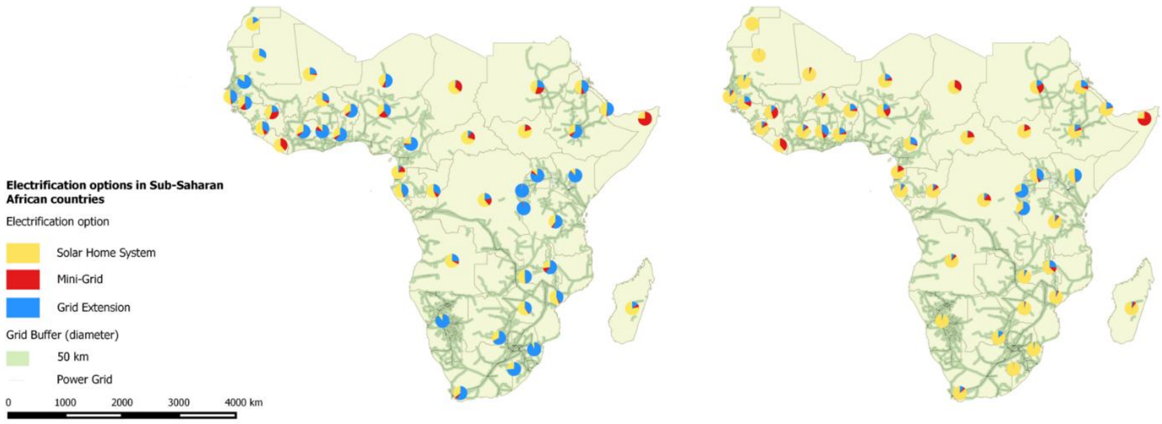


**Figure 5.** Geographic electrification options for excluding (**left**) and including (**right**) the population density within the grid buffer zone on basis of the existing grid infrastructure in sub-Saharan Africa.

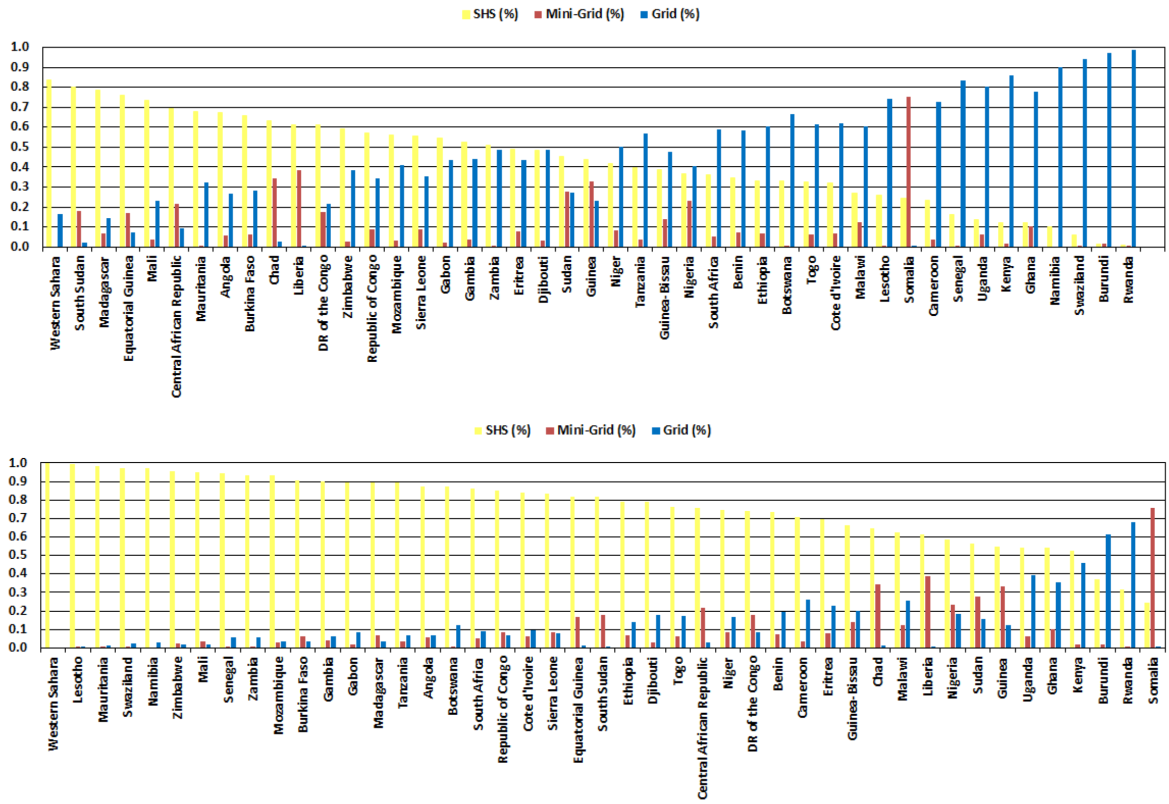


**Figure 6.** Population share of not yet electrified people to be electrified by SHS, mini-grids and grid extension for excluding (**top**) and including (**bottom**) the population density within the grid buffer zone on basis of the existing grid infrastructure for all countries in sub-Saharan Africa. The detailed numbers are provided in Tables A3 and A4.

In the second scenario we are considering the planned grid extensions on the African continent. When focusing on the grid-based case, the share of grid extension as the most favourable electrification option rises up to 61.6% of the currently undersupplied and covers an additional population of 26.1 million and 65.0 million covered in the first scenario by mini-grids or SHS respectively (Table 3). The results of the SHS based scenario are very remarkable. Under the assumption that grid connection costs exceed economic feasibility in very low populated areas we showcase that grid extension is only covering an additional population of 26.1 million which have been previously covered by mini-grids.

**Table 3.** Quantification of electrification options depending on excluding (grid-based) and including (SHS-based) the population density within the grid buffer zone based on the planned grid infrastructure.

| Electrification Options | Grid-Based | | | SHS-Based | | |
|---|---|---|---|---|---|---|
| | SHS | Mini-Grid | Grid | SHS | Mini-Grid | Grid |
| Share of not supplied population | 30.3% | 8.1% | 61.6% | 71.3% | 8.1% | 20.6% |
| Absolute population in million | 187.6 | 50.5 | 381.5 | 442.0 | 50.5 | 127.2 |

Detailed data for all sub-Sahara African countries is provided in form of disclosed numbers and a set of diagrams for all four applied scenarios in the Supplementary Materials and Tables A3 and A4.

## 5. Sensitivity Analysis

A sensitivity analysis was conducted for studying the effects of varying key parameters on the overall results presented above. The sensitivity analysis focuses on the following key parameters: *grid buffer*—determining the extension of the centralized transmission grid and *population threshold*—determining if SHS or mini-grids are deployed for electrification. For the sensitivity analysis we only took into account the existing grid infrastructure. For the grid buffer radius two sensitivity scenarios applying 10 km and 50 km as grid buffer radius were conducted and for the population threshold a sensitivity analysis was applied taking into account a population threshold of 100 persons per km$^2$.

For the grid based scenario a smaller grid buffer radius of 10 km leads to a higher share of SHS with 55.1% (+14.3 percentage points compared to the base scenario) and a reduced share of grid electrification with 26.9% (−20.0 percentage points compared to the base scenario). The effect on the mini-grid share is less strong with a share of 18.0% of the population. This is an additional share of 5.7% which is assigned for grid electrification in the base scenario (grid buffer 25 km) (Figure 7).

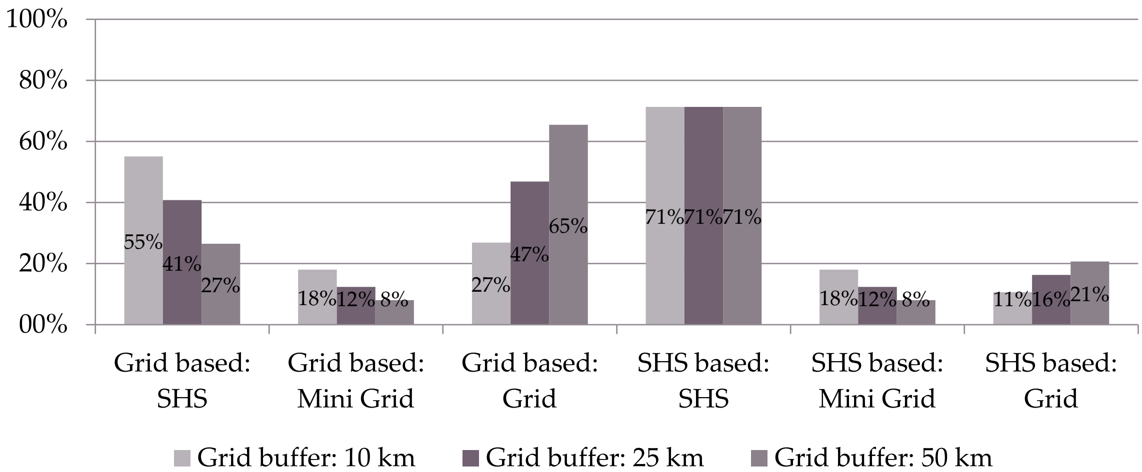


**Figure 7.** Results of sensitivity analysis for the parameter grid buffer radius. The bar diagram shows the results for all considered countries for a buffer radius of 10 km, 25 km (base scenario) and 50 km for grid based and SHS based scenarios.

A larger grid buffer radius of 50 km for the grid based scenario leads to reverted results: The grid as electrification option increases to a share of 65.5% (+18.6 percentage points) whereas mini-grids with 8.0% (−4.4 percentage points) and SHS with 26.5% (−14.3 percentage points) are decreasing as preferred electrification option (Figure 7).

For the SHS-based scenario the grid buffer radius has no effect on the share of SHS as electrification option since SHS are considered "under" the grid with the population threshold as the decisive parameter for deploying SHS or the grid as electrification option. Therefore the share remains equally high with 71.3% for each of the considered values (Figure 7). Consequently, only the shares for mini-grids and grid electrification are altering: If the grid buffer is set at 10 km the mini-grid share rises by 5.7 percentage points compared to the base scenario at the expense of the grid share. Vice versa when applying a grid buffer of 50 km the grid share rises by 4.4 percentage points at the expense of the mini-grid share (Figure 7).

Finally, we can summarize that varying the grid buffer radius has a significant impact on the SHS and grid share for the grid based scenario and lower impact on the mini-grid share. For the SHS based scenario altering the buffer radius leads to a minor impact solely on the shares of the mini-grids and grid electrification options.

For both grid and SHS based scenario the importance of mini-grids as electrification option rises with a lower population threshold of 100 persons per km$^2$. Compared to the base scenario, which considers a population threshold of 400 persons per km$^2$, an additional of 9.0% of the sub-Saharan African population is considered for obtaining electricity access through mini-grids. The share of SHS electrification decreases by the same value as the grid electrification is not influenced by the lower population threshold in the grid based scenario (Figure 8).

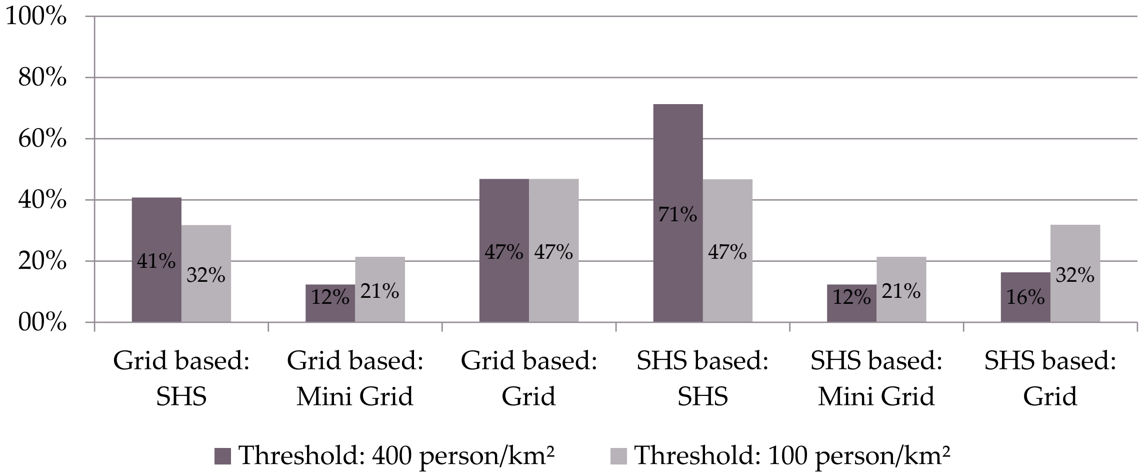


**Figure 8.** Results of sensitivity analysis for the parameter population threshold. The bar diagram shows the results for all considered countries for the base study with a threshold of 400 persons/km$^2$ (base scenario) and for comparison for a threshold of 100 person/km$^2$ for grid based and SHS based scenarios.

For the SHS-based scenario the impact of a lower population threshold is twofold: The share of SHS electrification decreases significantly to 46.7% (−24.6 percentage points compared to base scenario) since more areas are considered for mini-grid electrification (+9.0 percentage points) and additionally further areas within the grid buffer are considered for grid electrification (+15.6 percentage points) due to the lower population threshold (Figure 8).

Finally, we can derive that a lower population threshold would increase the relevance of mini-grids for rural electrification, but also for central grid extension. Both SHS and grid electrification still hold higher electrification shares and with this study we identify a significantly lower share of mini-grid electrification than stated by IEA with 45% [60].

## 6. Discussion

The presented results highlight the relevance of SHS for achieving universal energy access in sub-Saharan Africa as the share of SHS is at least 30.3% even in the most grid favourable scenario and would even reach 71% in the most SHS favorable scenario. Mini-grids instead contribute to proving electricity access to a rather small portion of the currently undersupplied in each of the scenarios (ranging from 8.1% to 12.4%). This contradicts estimations of the IEA which expect that mini-grid solutions will deliver 45% of connections for missionary electrification until 2040 [60]. Grid extension is the most preferable electrification option when considering the existing and planned grid and leaving the demographic structure of the covered areas out (46.9% and 61.6%). However, if the population density is taken into account the importance of the grid is significantly outweighed by the benefit of the SHS solution.

With our results we are aiming to highlight the complexity of developing electrification scenarios for sub-Saharan Africa. In this study we took the existing infrastructure, distances and population density into account. Certainly it is necessary to consider further parameters for determining the most feasible electrification option for a certain location such as load demands and cost structures.

From an economic perspective it is most important to take into account the necessary investment costs, renewable and conventional resource availability and energy demand structures. This would allow for comparing the different electrification options in terms of levelized costs for electricity (LCOE). Besides the necessary initial investments transportation costs for delivering technology or fuel (in the case of mini-grids) should be incorporated and can contribute to achieving a clearer picture of possible cost structures. The same is also applicable for grid extension. In our study we assume that the entire population in a zone of 25 km around the existing and planned grids could be connected. In this instance taking into account land cover, road networks and water bodies to the potential costs for grid extensions would allow for more precisely determining the costs of grid extension. Generally considering the lowest potential power generation costs allows the elimination of the decisive parameters of distance and population density applied in this study.

Another important aspect to consider in a future study is to discuss whether grid extension, mini-grids and solar home systems can be judged as comparable electrification options. Recent research highlighted that just having an electricity connection by one of the presented technological solutions is not a measure on the quality of the energy access for the households [61]. In addition, there are still some technical limitations on the use of SHS and it is questioned if SHS can supply productive loads. With regard to large demands (e.g., from productive use or newly introduced industries) grid based systems due to their broader technical reach are still considered as an important component for the transition up the energy access ladder [62].

## 7. Conclusions

The Sustainable Development Goal 7 sets a clear goal of bringing access to electricity to the complete population. The standard electrification option in the developed world is grid-connection for almost all households. This highly capital intensive electrification option may take far too long for developing countries to achieve a fast electrification and supply of basic electricity services. The technically well-established electrification option with mini-grids requires first of all a sufficient enough high local power demand density, which is a function of the population density and in addition substantial upfront investment cost which can imply long amortization periods and challenging financing needs and management capabilities. The basic electrification option using SHS requires comparably less capital investments, shows a fast amortisation and can diffuse comparably fast in rural areas. Based on these constraints a methodology has been developed and applied to sub-Saharan Africa to better understand the relevance of the different electrification options.

The methodology is based on geospatial night light imagery and population distribution plus grid infrastructure. It has been identified a major impact of the population density on the derived electrification options, since it may be questionable whether a sparsely populated area around power lines will be fast grid connected to power lines, given the extra investment and management requirements for transformers and additional branch ducts. This constraint may lead to about 190 million more people electrified by SHS, representing about one third of all unsupplied people. Therefore, the people to gain access to electricity by SHS range from 40.8% to 71.3%. The share of people electrified by mini-grids is not affected by this and is found to be around 12%, which equals to

76 million people. Grid extensions could be the most suited electrification option for 16% to 47% of the unsupplied population, depending on the willingness to connect also areas of a low population density to the grid.

Taking into account the planned grid expansions in sub-Saharan Africa approximately 91 million people more could be electrified by grid extensions. However, this result is relativized, if the population density is again taking into account, since then only 26 million people more could be electrified by grid extensions, instead of mini-grids.

Our results of 8.1% to 12.4% of people to be electrified with mini-grids are in stark contrast to estimates of the IEA, which estimates that 45% of electrification in sub-Saharan Africa will be achieved by mini-grids. The high SHS electrification share identified in our results implies its advantages as a potentially fast and comparably less capital intensive electrification pathway which can be more easily organised by private stakeholders and financed in a high share by the local population. These systems therefore do not need densely populated settlements compared to mini-grids and grid connections, which connect the customers via distribution grids. However the disadvantage may be limited commercial activities due to lack of powering machinery. Nevertheless, the optimised electrification strategy may require a two-step approach: first basic electrification via SHS and second, upgrades to local mini-grids after maximising the utilisation of SHS.

The results of this research indicate that a fast electrification of unsupplied people with SHS is needed to achieve SDG 7. This is based on the large rural areas of sub-Saharan Africa with many people living in scattered settlements far away from the grid. Mini-grids seem not to be a major electrification option, but changing the population threshold shows a higher deployment rate for mini-grids. Thus, with new technologies and business models which could reduce the costs of mini-grids, their implementation rate can be increased. Grid extensions are highly attractive for areas of high population density close to existing grid infrastructure. In summary, our study outlined different electrification scenarios which all underline that all three electrification options are needed to achieve 100% energy access in sub-Saharan Africa. The shares of the different options depend upon the speed of grid extension (defined by grid buffer) and the commercial viability of smaller mini-grids (defined by population threshold).

**Supplementary Materials:** The following are available online at www.mdpi.com/1996-1073/10/11/1899/s1.

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**Author Contributions:** Paul Bertheau carried out main parts of the research, including development of the methodology analysing the results and writing the manuscript. Ayobami Solomon Oyewo applied the methodology for all countries, analysed the results and visualized most of the figures. Catherina Cader developed the methodology and contributed much of the input data. Christian Breyer and Philipp Blechinger framed the research questions and scope of the work, checked the results, facilitated discussions, and reviewed the manuscript.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

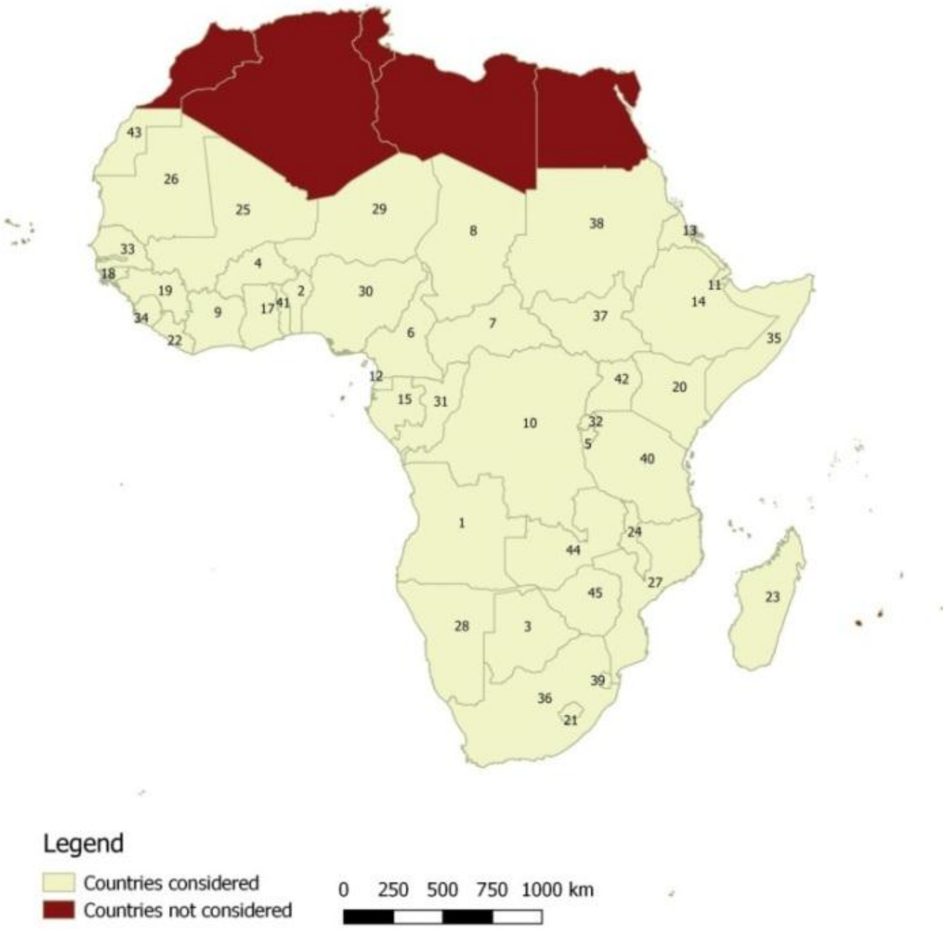


**Figure A1.** Sub-Saharan African countries selected for detailed geospatial analysis in this research. The numbers for the countries are identtified in Table A1.

**Table A1.** Sub-Saharan African countries investigated in detailed geospatial analysis in this research.

| No. | Name | ISO |
|---|---|---|
| 1 | Angola | AGO |
| 2 | Benin | BEN |
| 3 | Botswana | BWA |
| 4 | Burkina Faso | BFA |
| 5 | Burundi | BDI |
| 6 | Cameroon | CMR |
| 7 | Central African Republic | CAF |
| 8 | Chad | TCD |
| 9 | Côte d'Ivoire | CIV |
| 10 | DR Congo | COD |
| 11 | Djibouti | DJI |
| 12 | Equatorial Guinea | GNQ |
| 13 | Eritrea | ERI |
| 14 | Ethiopia | ETH |
| 15 | Gabon | GAB |

**Table A1.** *Cont.*

| No. | Name | ISO |
| --- | --- | --- |
| 16 | Gambia | GMB |
| 17 | Ghana | GHA |
| 18 | Guinea-Bissau | GNB |
| 19 | Guinea | GIN |
| 20 | Kenya | KEN |
| 21 | Lesotho | LSO |
| 22 | Liberia | LBR |
| 23 | Madagascar | MDG |
| 24 | Malawi | MWI |
| 25 | Mali | MLI |
| 26 | Mauritania | MRT |
| 27 | Mozambique | MOZ |
| 28 | Namibia | NAM |
| 29 | Niger | NER |
| 30 | Nigeria | NGA |
| 31 | Republic of Congo | COG |
| 32 | Rwanda | RWA |
| 33 | Senegal | SEN |
| 34 | Sierra Leone | SLE |
| 35 | Somalia | SOM |
| 36 | South Africa | ZAF |
| 37 | South Sudan | SSD |
| 38 | Sudan | SDN |
| 39 | Swaziland | SWZ |
| 40 | Tanzania | TZA |
| 41 | Togo | TGO |
| 42 | Uganda | UGA |
| 43 | Western Sahara | ESH |
| 44 | Zambia | ZMB |
| 45 | Zimbabwe | ZWE |

**Table A2.** Difference of calculated electrification rate (Night light band) to statistical electrification rate (IEA) in %.

| # | Country | E. Access Rate [52] | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Angola | 30% | 55% | 33% | 10% | 0% | −6% | −9% | −10% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −12% | −12% | −12% |
| 2 | Benin | 28% | 42% | 23% | 15% | 13% | 12% | 12% | 11% | 11% | 11% | 11% | 11% | 10% | 10% | 10% | 10% | 10% | 9% | 9% | 9% | 9% | 9% |
| 3 | Botswana | 66% | 33% | 33% | 32% | 27% | 16% | 1% | −9% | −13% | −13% | −13% | −13% | −14% | −14% | −14% | −14% | −14% | −14% | −15% | −15% | −15% | −15% |
| 4 | Burkina Faso | 16% | 79% | 73% | 63% | 51% | 36% | 23% | 15% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 9% | 9% | 9% | 9% |
| 5 | Burundi | 10% | 85% | 71% | 23% | 2% | 0% | 0% | 0% | −1% | −1% | −1% | −1% | −1% | −1% | −1% | −1% | −1% | −2% | −2% | −2% | −2% | −2% |
| 6 | Cameroon | 54% | −1% | −3% | −7% | −13% | −18% | −20% | −21% | −22% | −22% | −22% | −22% | −22% | −22% | −23% | −23% | −23% | −23% | −23% | −23% | −23% | −23% |
| 7 | CAR | 3% | 23% | 15% | 13% | 13% | 13% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% |
| 8 | Chad | 4% | 82% | 72% | 60% | 50% | 43% | 37% | 29% | 22% | 14% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 10% | 9% |
| 9 | Cote d'Ivoire | 26% | 32% | 23% | 21% | 20% | 19% | 19% | 19% | 19% | 18% | 18% | 18% | 18% | 18% | 18% | 17% | 17% | 17% | 17% | 17% | 17% | 17% |
| 10 | DRC | 9% | 42% | 27% | 15% | 10% | 9% | 9% | 9% | 9% | 9% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 7% |
| 11 | Djibouti | 50% | 50% | 50% | 50% | 49% | 41% | 26% | 20% | 17% | 16% | 16% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% | 15% |
| 12 | Eq. Guinea | 66% | −41% | −42% | −42% | −42% | −43% | −43% | −43% | −43% | −43% | −43% | −44% | −44% | −45% | −45% | −45% | −45% | −45% | −45% | −45% | −45% | −45% |
| 13 | Eritrea | 32% | 68% | 68% | 66% | 59% | 45% | 20% | −4% | −16% | −24% | −25% | −25% | −25% | −25% | −25% | −25% | −25% | −25% | −25% | −25% | −25% | −25% |
| 14 | Ethiopia | 23% | 34% | 19% | 9% | 1% | −4% | −8% | −10% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −11% | −12% | −12% | −12% | −12% | −12% | −12% |
| 15 | Gabon | 60% | 10% | 9% | 9% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 8% | 7% | 7% | 7% | 7% | 6% | 6% | 6% | 6% |
| 16 | Gambia | 35% | 58% | 47% | 32% | 20% | 14% | 13% | 13% | 13% | 13% | 13% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 11% |
| 17 | Ghana | 72% | 5% | −4% | −9% | −12% | −13% | −13% | −14% | −14% | −14% | −15% | −15% | −15% | −16% | −16% | −16% | −17% | −17% | −17% | −18% | −18% | −18% |
| 18 | Guinea | 12% | 34% | 20% | 16% | 14% | 13% | 13% | 12% | 12% | 12% | 12% | 12% | 12% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 10% | 10% |
| 19 | Guinea-Bissau | 20% | 40% | 22% | 12% | 8% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 6% | 5% | 5% | 5% | 5% |
| 20 | Kenya | 20% | 66% | 45% | 30% | 20% | 13% | 10% | 8% | 7% | 7% | 7% | 6% | 6% | 6% | 6% | 6% | 5% | 5% | 5% | 5% | 5% | 5% |
| 21 | Lesotho | 28% | 67% | 56% | 37% | 16% | 4% | −3% | −6% | −6% | −6% | −7% | −7% | −7% | −7% | −7% | −7% | −7% | −7% | −7% | −8% | −8% | −8% |
| 22 | Liberia | 2% | 28% | 26% | 25% | 25% | 24% | 24% | 23% | 23% | 23% | 23% | 23% | 22% | 22% | 22% | 22% | 21% | 21% | 21% | 21% | 21% | 21% |
| 23 | Madagascar | 15% | 56% | 46% | 28% | 14% | 9% | 7% | 6% | 6% | 6% | 6% | 6% | 6% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% | 5% |
| 24 | Malawi | 9% | 88% | 80% | 51% | 19% | 14% | 14% | 13% | 13% | 13% | 13% | 13% | 13% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 12% | 11% |
| 25 | Mali | 27% | 67% | 61% | 54% | 45% | 34% | 21% | 11% | 4% | −1% | −2% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% |
| 26 | Mauritania | 21% | 79% | 79% | 79% | 79% | 76% | 70% | 57% | 28% | 12% | 6% | 6% | 6% | 6% | 6% | 5% | 5% | 5% | 5% | 5% | 5% | 5% |
| 27 | Mozambique | 39% | 46% | 20% | −5% | −11% | −12% | −12% | −12% | −12% | −13% | −13% | −13% | −13% | −13% | −13% | −13% | −13% | −13% | −13% | −14% | −14% | −14% |
| 28 | Namibia | 30% | 70% | 70% | 70% | 68% | 60% | 49% | 35% | 19% | 14% | 14% | 14% | 13% | 13% | 13% | 13% | 13% | 12% | 12% | 12% | 12% | 11% |
| 29 | Niger | 14% | 86% | 86% | 85% | 85% | 82% | 76% | 63% | 27% | 6% | 4% | 4% | 4% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% | 3% |
| 30 | Nigeria | 45% | 38% | 31% | 24% | 17% | 12% | 6% | 2% | 0% | 0% | −1% | −1% | −1% | −1% | −2% | −2% | −2% | −2% | −3% | −3% | −3% | −3% |
| 31 | Republic Congo | 35% | 46% | 39% | 33% | 32% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 31% | 30% | 30% | 30% | 30% | 30% | 30% |
| 32 | Rwanda | 17% | 78% | 68% | 40% | 9% | −1% | −2% | −2% | −2% | −2% | −2% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −4% | −4% | −4% |
| 33 | Sao Tome and Principe | 59% | 4% | 2% | 0% | −2% | −2% | −2% | −2% | −2% | −2% | −3% | −4% | −6% | −8% | −8% | −8% | −8% | −8% | −9% | −9% | −9% | −9% |
| 34 | Senegal | 55% | 39% | 34% | 31% | 27% | 21% | 15% | 4% | −10% | −14% | −14% | −14% | −14% | −14% | −14% | −14% | −15% | −15% | −15% | −15% | −15% | −15% |
| 35 | Sierra Leone | 5% | 28% | 22% | 21% | 20% | 20% | 19% | 19% | 19% | 19% | 19% | 19% | 19% | 19% | 19% | 19% | 18% | 18% | 18% | 18% | 18% | 18% |
| 36 | Somalia | 15% | 81% | 77% | 75% | 69% | 60% | 52% | 40% | 21% | 8% | 5% | 5% | 5% | 5% | 5% | 4% | 4% | 4% | 4% | 4% | 4% | 4% |
| 37 | South Africa | 85% | 66% | 6% | −1% | −7% | −12% | −14% | −15% | −16% | −16% | −17% | −17% | −18% | −18% | −18% | −19% | −19% | −19% | −20% | −20% | −20% | −20% |
| 38 | South Sudan | 1% | 52% | 24% | 10% | 4% | 2% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% |
| 39 | Sudan | 35% | 63% | 60% | 56% | 52% | 46% | 37% | 26% | 11% | 0% | −3% | −3% | −3% | −3% | −4% | −4% | −4% | −4% | −4% | −4% | −4% | −4% |
| 40 | Swaziland | 27% | 67% | 57% | 41% | 32% | 30% | 28% | 26% | 24% | 23% | 22% | 21% | 20% | 19% | 18% | 17% | 16% | 15% | 15% | 14% | 13% | 13% |
| 41 | Tanzania | 24% | 67% | 59% | 43% | 28% | 13% | 2% | −2% | −2% | −2% | −2% | −2% | −2% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% | −3% |
| 42 | Togo | 27% | 49% | 32% | 20% | 14% | 13% | 13% | 12% | 12% | 12% | 11% | 11% | 11% | 11% | 10% | 10% | 10% | 9% | 9% | 9% | 9% | 9% |
| 43 | Uganda | 15% | 62% | 34% | 13% | 4% | 2% | 2% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 1% | 0% | 0% | 0% | 0% | 0% | 0% |
| 44 | Zambia | 26% | 67% | 51% | 30% | 17% | 13% | 12% | 12% | 12% | 12% | 12% | 12% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% | 11% |
| 45 | Zimbabwe | 40% | 58% | 52% | 36% | 17% | 1% | −6% | −7% | −7% | −8% | −8% | −8% | −8% | −8% | −8% | −8% | −8% | −8% | −8% | −8% | −9% | −9% |

**Table A3.** Results on a country basis for the grid based scenario (excluding population density in the gird buffer zone).

| Country | Not Supplied Population (in Million) | Existing Grid | | | Planned Grid | | |
|---|---|---|---|---|---|---|---|
| | | SHS | Mini-Grid | Grid | SHS | Mini-Grid | Grid |
| Angola | 9.9 | 67% | 6% | 27% | 46% | 3% | 50% |
| Burundi | 8.2 | 1% | 2% | 97% | 1% | 1% | 98% |
| Benin | 6.5 | 34% | 7% | 58% | 20% | 3% | 77% |
| Burkina Faso | 13.1 | 66% | 6% | 28% | 31% | 3% | 66% |
| Botswana | 0.7 | 33% | 1% | 66% | 31% | 1% | 68% |
| Central African Republic | 4.1 | 69% | 21% | 9% | 54% | 17% | 28% |
| Cote d’Ivoire | 11.7 | 32% | 6% | 62% | 29% | 6% | 65% |
| Cameroon | 9.7 | 24% | 4% | 73% | 17% | 3% | 80% |
| DR Congo | 61.1 | 61% | 18% | 21% | 36% | 6% | 59% |
| Republic of Congo | 1.6 | 57% | 9% | 34% | 33% | 6% | 62% |
| Djibouti | 0.3 | 48% | 3% | 48% | 28% | 2% | 70% |
| Eritrea | 4.2 | 49% | 8% | 43% | 40% | 5% | 54% |
| Western Sahara | 0.3 | 84% | 0% | 16% | 78% | 0% | 22% |
| Ethiopia | 68.2 | 33% | 7% | 60% | 25% | 5% | 70% |
| Gabon | 0.5 | 55% | 2% | 43% | 31% | 2% | 67% |
| Ghana | 7.6 | 12% | 10% | 78% | 8% | 8% | 84% |
| Guinea | 9.2 | 44% | 33% | 23% | 23% | 17% | 60% |
| Gambia | 1.0 | 52% | 4% | 44% | 36% | 3% | 61% |
| Guinea-Bissau | 1.3 | 39% | 14% | 48% | 31% | 10% | 59% |
| Equatorial Guinea | 0.6 | 76% | 17% | 7% | 39% | 7% | 54% |
| Kenya | 33.5 | 12% | 2% | 86% | 10% | 1% | 89% |
| Liberia | 3.2 | 61% | 39% | 0% | 35% | 11% | 54% |
| Lesotho | 1.4 | 26% | 0% | 74% | 26% | 0% | 74% |
| Madagascar | 19.3 | 79% | 7% | 15% | 58% | 6% | 36% |
| Mali | 11.5 | 73% | 4% | 23% | 65% | 3% | 33% |
| Mozambique | 16.7 | 56% | 3% | 41% | 49% | 2% | 49% |
| Mauritania | 3.0 | 68% | 0% | 32% | 50% | 0% | 50% |
| Malawi | 14.1 | 27% | 12% | 61% | 19% | 10% | 71% |
| Namibia | 1.5 | 10% | 0% | 90% | 8% | 0% | 92% |
| Niger | 14.8 | 42% | 8% | 50% | 36% | 7% | 57% |
| Nigeria | 96.2 | 37% | 23% | 40% | 29% | 18% | 53% |
| Rwanda | 8.2 | 1% | 1% | 98% | 0% | 0% | 100% |
| Sudan | 22.1 | 45% | 28% | 27% | 41% | 25% | 34% |
| Senegal | 6.0 | 16% | 0% | 84% | 12% | 0% | 88% |
| Sierra Leone | 4.6 | 56% | 9% | 36% | 42% | 7% | 51% |
| Somalia | 8.3 | 25% | 75% | 0% | 20% | 44% | 35% |
| South Sudan | 11.3 | 80% | 18% | 2% | 51% | 6% | 43% |
| Swaziland | 0.8 | 6% | 0% | 94% | 6% | 0% | 94% |
| Chad | 11.1 | 63% | 34% | 3% | 58% | 30% | 12% |
| Togo | 4.1 | 32% | 6% | 61% | 22% | 5% | 73% |
| Tanzania | 41.4 | 40% | 4% | 57% | 33% | 3% | 64% |
| Uganda | 33.2 | 13% | 6% | 81% | 7% | 3% | 90% |
| South Africa | 16.3 | 36% | 5% | 59% | 32% | 5% | 63% |
| Zambia | 9.4 | 51% | 1% | 48% | 41% | 1% | 59% |
| Zimbabwe | 7.8 | 59% | 2% | 38% | 49% | 1% | 49% |

**Table A4.** Results on a country basis for SHS based scenario (including population density in the gird buffer zone).

| Country | Not Supplied Population (in Million) | Existing Grid | | | Planned Grid | | |
|---|---|---|---|---|---|---|---|
| | | SHS | Mini-Grid | Grid | SHS | Mini-Grid | Grid |
| Angola | 9.9 | 87% | 6% | 7% | 87% | 3% | 9% |
| Burundi | 8.2 | 37% | 2% | 61% | 37% | 1% | 62% |
| Benin | 6.5 | 73% | 7% | 19% | 73% | 3% | 23% |
| Burkina Faso | 13.1 | 90% | 6% | 4% | 90% | 3% | 6% |
| Botswana | 0.7 | 87% | 1% | 12% | 87% | 1% | 12% |
| Central African Republic | 4.1 | 76% | 21% | 3% | 76% | 17% | 7% |
| Cote d'Ivoire | 11.7 | 84% | 6% | 9% | 84% | 6% | 10% |
| Cameroon | 9.7 | 71% | 4% | 26% | 71% | 3% | 27% |
| DR Congo | 61.1 | 74% | 18% | 9% | 74% | 6% | 21% |
| Republic of Congo | 1.6 | 85% | 9% | 7% | 85% | 6% | 10% |
| Djibouti | 0.3 | 79% | 3% | 18% | 79% | 2% | 19% |
| Eritrea | 4.2 | 70% | 8% | 23% | 70% | 5% | 25% |
| Western Sahara | 0.3 | 100% | 0% | 0% | 100% | 0% | 0% |
| Ethiopia | 68.2 | 79% | 7% | 14% | 79% | 5% | 16% |
| Gabon | 0.5 | 90% | 2% | 8% | 90% | 2% | 8% |
| Ghana | 7.6 | 54% | 10% | 36% | 54% | 8% | 38% |
| Guinea | 9.2 | 55% | 33% | 12% | 55% | 17% | 28% |
| Gambia | 1.0 | 90% | 4% | 6% | 90% | 3% | 7% |
| Guinea-Bissau | 1.3 | 66% | 14% | 20% | 66% | 10% | 24% |
| Equatorial Guinea | 0.6 | 82% | 17% | 1% | 82% | 7% | 11% |
| Kenya | 33.5 | 52% | 2% | 46% | 52% | 1% | 46% |
| Liberia | 3.2 | 61% | 39% | 0% | 61% | 11% | 28% |
| Lesotho | 1.4 | 99% | 0% | 1% | 99% | 0% | 1% |
| Madagascar | 19.3 | 90% | 7% | 4% | 90% | 6% | 5% |
| Mali | 11.5 | 95% | 4% | 2% | 95% | 3% | 2% |
| Mozambique | 16.7 | 93% | 3% | 4% | 93% | 2% | 4% |
| Mauritania | 3.0 | 98% | 0% | 1% | 98% | 0% | 2% |
| Malawi | 14.1 | 62% | 12% | 25% | 62% | 10% | 27% |
| Namibia | 1.5 | 97% | 0% | 3% | 97% | 0% | 3% |
| Niger | 14.8 | 75% | 8% | 17% | 75% | 7% | 18% |
| Nigeria | 96.2 | 58% | 23% | 18% | 58% | 18% | 24% |
| Rwanda | 8.2 | 31% | 1% | 68% | 31% | 0% | 68% |
| Sudan | 22.1 | 57% | 28% | 16% | 57% | 25% | 19% |
| Senegal | 6.0 | 94% | 0% | 6% | 94% | 0% | 6% |
| Sierra Leone | 4.6 | 83% | 9% | 8% | 83% | 7% | 10% |
| Somalia | 8.3 | 25% | 75% | 0% | 25% | 44% | 31% |
| South Sudan | 11.3 | 82% | 18% | 1% | 82% | 6% | 13% |
| Swaziland | 0.8 | 97% | 0% | 3% | 97% | 0% | 3% |
| Chad | 11.1 | 65% | 34% | 1% | 65% | 30% | 5% |
| Togo | 4.1 | 76% | 6% | 18% | 76% | 5% | 18% |
| Tanzania | 41.4 | 90% | 4% | 7% | 90% | 3% | 8% |
| Uganda | 33.2 | 54% | 6% | 40% | 54% | 3% | 42% |
| South Africa | 16.3 | 86% | 5% | 9% | 86% | 5% | 10% |
| Zambia | 9.4 | 94% | 1% | 6% | 94% | 1% | 6% |
| Zimbabwe | 7.8 | 96% | 2% | 2% | 96% | 1% | 3% |

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