Analysis of the African Electricity Infrastructure with Focus for the Use of Wind and Solar Potentials

Robert Gaugl, Udo Bachhiesl, Lukas Frauenlob

Institute of Electricity Economics and Energy Innovation / Graz University of Technology, Inffeldgasse 18/II, A-8010 Graz

Abstract: Information about the existing electricity infrastructure in Africa of the Open Street Map (OSM) project is processed to reduce the very large original data set, with great care taken that no important data is inadvertently lost. The mean solar incoming shortwave (SIS) radiation between 1983 and 2017 is calculated using a Geographic Information System (GIS) analysis. The resulting data, as well as existing wind data is superimposed with the simplified grid data from OSM to identify regions with high solar/PV and wind potentials and pre-existing electricity infrastructure.

Keywords: Renewable Energies, Africa, Wind, Solar, Transmission Grid, GIS Analysis

1 Introduction

The African continent has large identified potentials for solar/photovoltaic (PV) and wind. According to IRENA [1], the theoretical potential in the whole continent for concentrated solar power (CSP) is 470 PWh, 660 PWh for PV and 460 PWh for wind. The Carbon dioxide (CO₂) emissions from Africa are currently smaller compared to other regions like Europe. Although Africa roughly has double the population of Europe (1 305 million people in Africa compared to 746 million in Europe [2]) the CO₂ emissions are only about one third of Europe (Africa: 1 235.5 Mt, Europe: 4 209.3 Mt in 2018 [3]). The predicted growth of the African population, associated with a higher energy demand, as well as the desire to get a higher standard of living could lead to a sharp rise of CO₂ emissions in the future. A sustainable development which uses the renewable energy potentials of the continent to prevent further climate change would be of global interest.

In order to explore how solar/PV and wind potentials could be used with the existing electricity infrastructure and where further investments would be needed, data for solar radiation and wind speeds are used and the existing electricity infrastructure is laid on top of it using a Geographic Information System (GIS) approach.

2 Methodology

There are three main data points that have to be compiled for this research:

- 1) The existing electricity infrastructure,
- 2) the solar radiation and
- 3) the wind speed data.

The following subchapters go into detail how these data points have been collected and/or calculated.

2.1 Electricity Infrastructure

In Europe, data for the electricity grid can be found on the website of the European Network of Transmission System Operators for Electricity (ENTSO-E) or is readily available from the Transmission System Operators (TSOs) themselves. Information about the African electricity infrastructure is scarce and difficult to find. Therefore, the data from the Open Street Map (OSM) project is used. OSM uses crowdsourced information and makes it available under the Open Database License. Figure 1 shows the available grid data with transmission lines of 110 kV and above for Africa from OSM.



Figure 1: Electricity infrastructure from open Street Map [4] with all lines of 110 kV and above.

This data can be downloaded in the .jason file format. Each line (called "way") is made up of two or more nodes and contains information about the voltage level, number of systems etc. The nodes represent start- and end-points of a line as well as pylons. Figure 2a shows an example of how a substation looks like in the OSM data. In Figure 2b all the lines with the corresponding nodes have been highlighted in red. The level of detail of the information from OSM is seen to be very high. For this research, the data needs to be simplified: First, the substations are reduced to a single node. This is done by grouping nodes which are within a set threshold. Second, only the start- and end-points of a power line are of interest, and therefore the additional nodes are deleted from the data set. Figure 2c shows the simplified data set for this example. The lines in OSM also have information about the number of systems per way element. In order to display the right amount of systems, way elements with two systems get doubled, way elements with three systems get tripled and so on (see Figure 2d). Detailed information about the extraction of the information from the OSM data can be found in the master thesis "*Optimized modeling of energy infrastructures using automated data selection*" from Lukas Frauenlob [5].



Figure 2: The steps from the OSM data to the simplified version.

Four of the five major power pools that make up the African electricity system can be observed in the resulting data in Figure 3: The Northern African Power Pool (NAPP), the Eastern African Power Pool (EAPP), the Southern African Power Pool (SAPP) and the Western African Power Pool (WAPP). As can be seen, there are only a few lines connecting the different Power Pools and therefore the transfer capacities between the Power Pools are really limited.

It is noticeable that the electricity infrastructure mainly covers the shoreline, where most of the people live. Inside the continent there is little to no existing infrastructure that can be used to connect solar/PV or wind power plants to the grid.



Figure 3: The resulting African transmission grid and the African Power Pools.

2.2 Solar Data

The potentials for solar energy are calculated using the monthly mean surface incoming shortwave (SIS) radiation between 1983 and 2017 from the Climate Monitoring Satellite Application Facility (CMSAF) [6]. This data has a high spatial resolution of $0.05^{\circ} \times 0.05^{\circ}$ degrees. Using ArcMaps¹, this monthly data was used to calculate the mean value for each year, and the result of that was used to calculate the mean SIS radiation from 1983 to 2017. The mean radiation ranges from 135 W/m² (\triangleq 1 182.6 kWh/m²)² in the area of Gabon, Equatorial Guinea and Republic of Congo to 290 W/m² (\triangleq 2 540.4 kWh/m²) in the Saharan desert as shown in Figure 4. Blue areas show locations with little SIS radiation and therefore smaller solar/PV potentials, whereas red areas indicate locations with higher potentials.

 $^{2} 1 W/m^{2} \cdot (24 h/day) = (24 Wh/m^{2})/day \cdot (365 days/year) = 8.760 kWh/m^{2}/year$

¹ ArcMaps is a program for processing geographic information data and is part of the ArcGIS Suite from ESRI.



Figure 4: Mean surface incoming shortwave (SIS) radiation between 1983 and 2017 in W/m^2 . Based on SIS data from [6].

2.3 Wind Data

The mean wind speed at a height of 100 m is obtained from the Global Wind Atlas 3.0 [7]. It can be seen, that there are some areas well suited for generation from wind power. Especially the Western Sahara, the Gulf of Suez and Kenya are areas with average wind speeds of 9 m/s and above. Similarly, in Algeria and Libya places with wind speeds of over 8 m/s could be utilized for electricity generation from wind power plants.



Figure 5: Mean wind speed at 100 m in m/s. Data from [7].

3 Results

In order to see which areas with high solar radiation and wind speeds are already covered by the existing electricity grid, the resulting maps are superimposed with the grid data from chapter 2.1.

Figure 6 shows that the highest potential for solar/PV is in the area of the Saharan desert (a), the west coast of Angola and Namibia (b) and Kenia and Somalia (c).

Due to the fact that the Saharan desert is sparsely populated, there is little existing electricity infrastructure. In order to use the potential for the larger grid³, addition to the costs of the PV/CSP, investments into new transmission lines are necessary. High voltage direct current (HVDC) lines would be the best option to transport the electricity from the production site to the demand centres. Although the solar radiation in the Saharan desert is well suited to be used for PV/CSP, the high temperatures in the desert reduce overall the efficiency of the PV cells and the moving sand demands cleaning of the PV panels and the mirrors from CSP. The area in Angola and Namibia have some grid connections, so the potential could be used more easily there.



Figure 6: Mean SIS radiation [6] with superimposed grid data [4].

³ In microgrids solar and wind power plants are already used in these areas.

Illustrated in Figure 7 is the mean wind speed at a height of 100 m above ground, overlaid with the transmission grid data. If only the onshore potential is considered⁴, the areas with higher wind speeds are located in the northern part of the continent. More specifically around Western-Sahara (a), areas in the Saharan desert (b) and around the lake Turkana in Kenya. It can be seen hat the wind potential in the Saharan desert overlaps with the solar/PV potential, and therefore has the same challenge of missing electricity infrastructure. In Egypt, around the river Nile, is some infrastructure present. Kenya is already building the Lake Turkana Wind Power Station which aims to install 310.25 MW to use the wind potential in that region [8].



Figure 7: Overlay of the grid data [4] on top of the mean wind speed at 100 m [7].

4 Conclusion and Outlook

The African continent has large potentials for solar/PV and wind, reaching up to 290 W/m² of mean SIS radiation and mean wind speeds of over 8 m/s in 100 m which are well suited for wind power plants.

Since the regions with high solar radiation are not very human-friendly, these are sparsely populated and accordingly there is little existing electricity infrastructure. For areas with higher wind speeds that are close to populated areas (like lake Turkana) wind power plants are already considered or built. As with the areas of high solar radiation in the Saharan desert, transmission lines in the form of HVDC lines would be necessary to connect the power stations with the grid. These additional expanses make profitability of solar/PV and wind power plants a challenge.

⁴ Due to the higher costs of off-shore wind power plants it makes sense to utilize the on-shore potential first.

Currently Africa's electricity generation is mainly dependent on fossil fuels. According to the African Energy Outlook 2019 [9] from the International Energy Agency (IEA) 600 million people in Africa do not have access to electricity. With the motivation to get that number smaller, increasing population in Africa, and a desire to reach a higher standard of living, the electricity demand is predicted to grow from 185 kWh per capita today to over 430 kWh per capita in 2040 [9]. To cover this additional demand in a sustainable way, the solar/PV and wind potentials have to be used, and therefore investments to utilize the potentials in remote areas are needed.

In a next step, the grid data from OSM will be implemented into the ATLANTIS simulation model. Once the power plant park of the African continent and additional information about the electricity system of Africa is added, simulations can be conducted. The model will then be calibrated using information from the available electricity production data from the IEA. Subsequently, different scenarios can be simulated to see which options are the best for sustainable electricity generation in the African continent.

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