GEOSPATIAL PLANNING FOR THE RURAL ELECTRIFICATION OF THE AMAZON - SURINAME CASE STUDY

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RESUMO

A zona rural na Amazônia é uma das regiões da América do Sul com a menor taxa de acesso à eletricidade. Sistemas de informação geográfico com a dispersão populacional, infraestrutura atual de geração, transmissão e distribuição de energia elétrica, características e especificidades socioeconômicas das comunidades, além de dados ambientais e geofísicos, podem ser usados para planejar projetos de eletrificação rural. Ferramentas geoespaciais de código fonte aberto e dados abertos podem ser usadas para este planejamento. O "*Energy Access Explorer* (EAE)" é uma plataforma geoespacial interativa que usa análise multicritério espacial para identificar áreas prioritárias para intervenção de acesso à energia. Complementar ao EAE, o "*Open Source Spatial Electrification Tool* (OnSSET)" é uma ferramenta geoespacial desenvolvida para identificar a opção de eletrificação rural com o menor custo para as comunidades rurais, escolhendo entre as opções de extensão da rede de distribuição, instalação de mini redes com geração descentralizada ou instalações domiciliares individuais. Este trabalho apresenta um estudo de caso de Suriname usando EAE para priorizar áreas e comunidades prioritárias para instalação de projetos de eletrificação, e OnSSET para estimar o custo nivelado de energia para as diversas opções de atendimento dessas regiões. O resultado mostra que EAE pode ser usado como uma ferramenta de seleção de prioridade para políticas públicas e assim diminuir a interferência política. A metodologia *bottom-up* usada no EAE e OnSSET para Suriname podem ser usadas para outras regiões na Amazônia, com as mesmas densidades populacionais e padrões de ocupação geográficas.

Palavras-chave: Eletrificação rural; Amazônia; Energy Access Explorer; OnSSET.

ABSTRACT

The rural Amazon region is one of the regions in South America with the lowest rural electrification rates. Geographic information system with population distribution, current infrastructure for generation, transmission and distribution of electricity, and communities' socio-economic characteristics, in addition to environmental and geophysical data can be used to plan rural electrification projects. Two open-source and open-data geospatial tools can be used for this planning. The Energy Access Explorer (EAE) is an interactive geospatial platform that uses spatial multi-criteria analysis to identify priority areas for energy access interventions. Complementing the EAE, the Open Source Spatial Electrification Tool (OnSSET) is a geospatial tool developed to identify the least-cost electrification options for rural communities, choosing between the options of extending the distribution grid, installing mini-grids with decentralized generation or individual household installations with different energy sources. This paper presents a case study of Suriname using EAE to identify priority areas for the installation of rural electrification projects and OnSSET to estimate the most cost-effective electrification option for the achievement of electricity access goals. The result showed that the EAE's methodology can be used as a priority selection tool for public policy and decision making and so decrease the influences of politics. OnSSET was then used to determine the leveled energy cost and necessary investment for the various service options in these priority regions. This bottom-up methodology used in EAE and OnSSET for Suriname can be used for other regions with the same population densities and geographic occupation patterns in the Amazon.

Keywords: Rural electrification; Amazônia; Energy Access Explorer; OnSSET.

1. INTRODUÇÃO

The rural Amazon region is one of the regions in South America with the lowest rate of access to clean, universal, reliable, modern and affordable energy services. This situation is due to the characteristics of its human rural occupations, the relatively large dispersion of human communities across an immense territory and the geophysical characteristics of the territory itself. However, the region has a significant potential for renewable energy from solar, wind, water and biomass. Paradoxically, the rural area of the Amazon exports clean electrical energy coming from dozens of large hydroelectric plants to the large cities and consumer centers in the region and also outside the Amazon.

Rural electrification planning can be done with geospatial tools using a georeferenced database organized in a geographic information system with population distribution, current infrastructure for generation, transmission and distribution of electricity, and communities' socio-economic characteristics, in addition to environmental and geophysical data.

This paper presents two open-source and open-data geospatial tools namely: Energy Access Explorer (EAE) and Open Source Spatial Electrification Tool (OnSSET) that can be used for this planning and a case study for Suriname.

2. GEOSPATIAL PLANNING

The use of Geographic Information Systems (GIS) and remote sensing techniques has been increasingly used in energy planning and rural electrification. The GIS makes it possible to systematize data on spatialized energy demand and also the infrastructure for generation, transmission and distribution of electrical energy. Organizing this data into layers in a GIS allows to overlay supply and demand data along with socio-environmental conditions or restrictions in a very simple way. Through multi-criteria analyses, it is possible to assess various electrification alternatives or strategies.

2.1 Energy Access Explorer

The Energy Access Explorer (EAE) is an online, interactive, open-source platform, developed by the World Resource Institute. EAE enables energy planners, clean energy entrepreneurs, donors and development institutions to identify high-priority areas for energy access interventions. The platform uses spatial multi-criteria analyses to identify these high-priority areas (WRI, 2025).

Energy Access Explorer aggregates geospatial data related to both energy demand and supply. More specifically, data on demographics and the social and productive uses of electricity are used to represent current and potential demand. Furthermore, energy resource availability and infrastructure data are used to visualize current and potential supply. The datasets of demand and supply are shown in Figure 1 (MENTIS, 2019).

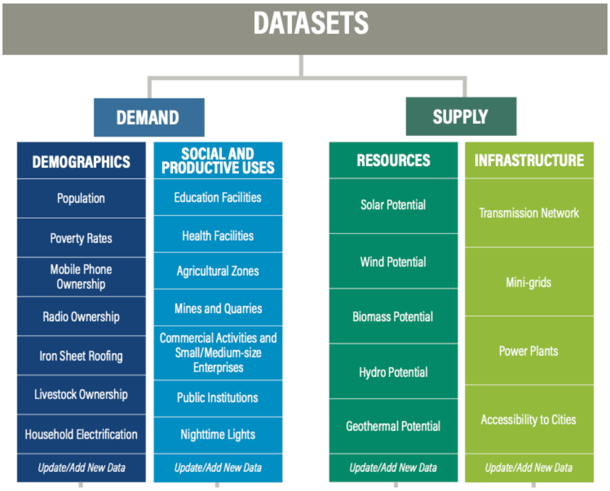

Figure 1 - Datasets of enery demand and supply

Energy Access Explorer is a multi-criteria analysis (MCA) tool to identify areas of interest to expand energy access. Within the online EAE platform the indicators from each dataset are normalized to a scale of zero (0) to one (1) according to predefined thresholds and can be customized in the content management system of the platform by the platform administrators. The MCA produces four indices: Energy Access Potential, Demand Index, Supply Index, and Need for Assistance Index. All indices are calculated for each square kilometer (km2) of the selected geography. This allows each square kilometer to have a distinct value, providing a detailed map of the area of interest (MENTIS et al. 2019).

The EAE user can customize the selection of dataset overlays and apply buffer zones and distance filters for each dataset. It is also possible to include weight criteria for the datasets. Figure 2 (MENTIS, 2019) shows the overall flowchart to obtain the energy access maps.

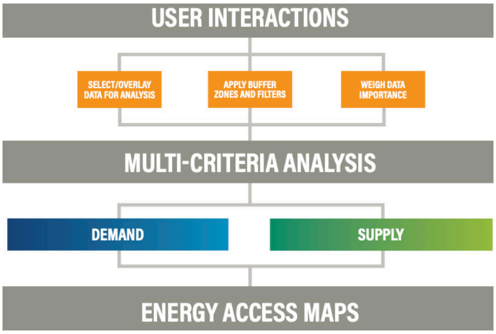

Figure 2 - Rationale of the multi-criteria analyses

The MCA then produces the energy access maps based on the four indices and indicates the priority areas.

2.2 Open Source Spatial Electrification Tool

The Open Source Spatial Electrification Tool (OnSSET) is a comprehensive, open-source platform that can estimate, analyze, and visualize the most cost-effective electrification options, including grid, mini-grid, and stand-alone solutions. It is designed to assess and deploy both conventional and renewable energy technologies. The aim of this tool is to achieve electricity access goals and to ensure affordable, reliable, sustainable, and modern energy access for all (KTH, 2025).

OnSSET uses the same datasets resource and infrastructure supply datasets as EAE. Additionally, OnSSET uses a population geospatial model and electricity access tiers to project the electricity demand for a given period and for every demand point in the GIS. The tools calculate the levelized cost of electricity from grid extension, solar, wind, hydropower and for all demand points in the GIS. Based on the cost, the best economic alternative to supply the demand is chosen for each demand point. Figure 3 (MENTIS, 2017) shows the framework of the tool.

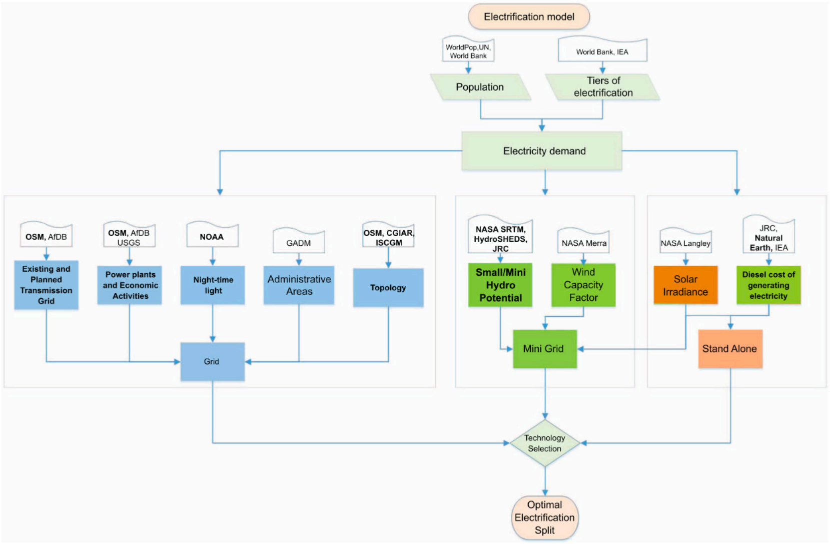

Figure 3 - Framework OnSSET toolkit

Besides this, OnSSET also calculates the necessary investment to implement the electrification supply.

3. CASE STUDY - SURINAME

Suriname is one of the smallest countries in the north of South America with an area of 162,000 km2. Although it is not an Island in the Caribbean Sea, it is considered part of the Caribbean Community due to its historical, cultural and socio-economic similarities with the other Caribbean nations. But Suriname is also part of the Amazonian tropical rainforest. It is not considered Latin America because the language is neither Portuguese nor Spanish.

The total population of Suriname is 620,000 inhabitants of which approximately 70% live in the coastal region, mainly in the capital city of Paramaribo and urban surroundings. The other 30% live in small cities and the rural areas in the highlands in the South of Suriname.

The overall rate of access to the utility's electricity services is 94%. The other 6% has some kind of precarious services provided by decentralized generation with small diesel generators. These diesel generators and their respective mini-grids in the larger villages in the highlands of Suriname are maintained by the government, which also provides quotas of fuel so that they can have 4 to 6 hours of electricity at night (FELIX and ELS, 2018). The smaller villages and settlements rely on their community initiatives.

There are hundreds of villages, settlements and camps in the Amazonian rainforest in the highland of Suriname with mainly indigenous and tribal people who make a living with shifting cultivating agriculture and forest products. The tribal people, or Maroons, are descendants of enslaved Africans, who were brought to the Americas in three centuries of slavery and slave trade, and managed to escape from slavery and re-create communal life in the tropical Amazonian rainforest. The tribal people nowadays stand for more than 20% of the total Suriname population, while the indigenous are around 5%.

In all these settlements or villages there are locally available energy sources from sun, wind, water and biomass that can be used to generate electricity through decentralized conversion systems.

One of the main challenges is to identify and map all of these renewable energy potentials, as they are widespread in a large area.

The EAE platform was used to identify and map Indigenous and tribal villages without access to regular electricity services and through a spatial multi-criteria analysis prioritize potential locations and technologies for the rural electrification of Suriname.

3.1 EAE Multi criteria Analyses for Suriname

The data from the demand side is demographic data that was obtained from Open Spatial Demographic Data and Research (WORLDPOP, 2025) databases and was processed as a raster format to obain a resolution of one square kilometer; it was based on the 2020 population census/projection-based estimation. Besides this demographic raster, a database with rural settlements from Suriname was obtained by the National Land Monitoring System of Suriname (GONINI, 2025). This vector file contained all the rural villages, settlements and other anthropic sites, indicating if it is an Amerindian or Tribal Maroon occupation. The dataset does not give the size of the population.

On the supply side, the wind velocity and solar Global Horizontal Irradiation were obtained from the open data sources Global Solar Atlas and Global Wind Atlas (SOLARGIS, 2025) and were also uploaded into the Energy Access Explorer. A vector file with the location of micro and small hydropower potential sites (ELS, 2020) was also uploaded to the platform. The existing electric energy infrastructure with locations of distribution substations and lines and transmission substations and lines were also uploaded in vector format into the platform. These vector files were also elaborated by the authors from existing maps in Suriname.

In order to obtain the areas in Suriname without access to the grid's electricity services some filters were included in the supply side datasets (Table 1 - ELS, 2024) and also a filter was implemented in the villages and settlements dataset to consider only the area within a radius of 2 km of the location (ELS, 2024).

Table 1 – Filters of dataset

Side	Dataset	Distance to location
Supply	Distribution substations	> 5 km
Supply	Distribution lines	> 2 km
Supply	Existing mini-grids	> 5 km
Demand	Villages and settlements	< 2 km

With these constraints, the multi-criteria spatial analysis was performed.

3.1.1 Results EAE

The result of the Energy Access Explorer is shown in Figure 4, with the map of the settlements and the priority areas indicated by the platform. The analysis resulted in a population share of 27,237 people that attended the criteria of the platform in an area of 4,486 km2. Besides this visual geospatial result, the platform calculates four indexes: The energy access potential, the demand index, the supply index and the assistance need index for the population density and for the area.

The most important result of the multi-criteria geospatial analyses is the list of sites with the top 20 locations. This is obtained by listing the sites that attend 80-100% of the criteria. This information can also be seen in Figure 4 (ELS, 2024) and shows that the highest scores were obtained by 19 tribal villages in the Upper-Suriname River Resort and by one Indigenous village in the Galibi Resort. The indigenous village in the Galibi Resort has a potential for solar and wind energy.

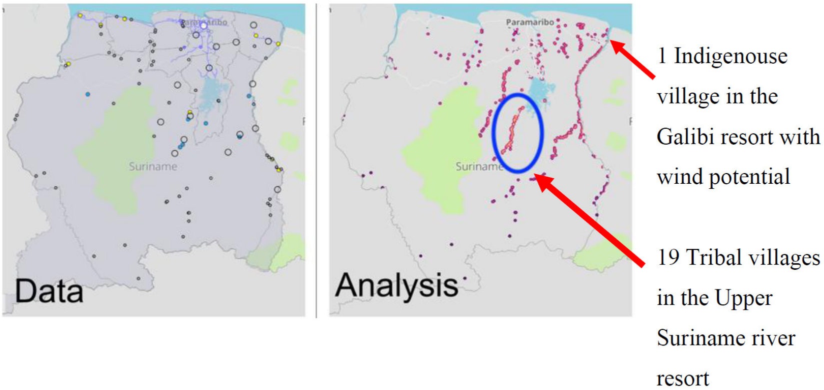

Figure 4 - EAE results with data of settlements and analyses with priority areas

Upper-Suriname River resort in the district of Sipaliwini has a high concentration of Tribal Villages with a population of more than 20,000 inhabitants and solar and micro hydropower potentials. This shows that this resort is by far the priority area for implementing rural electrification projects.

3.2 OnSSET analyses for Suriname

The OnSSET analysis was done for the entire country with a start year of 2020 and an end year of 2030. The purpose of this study was to determine the least-cost electrification option in urban – and rural areas of Suriname to get a 100% electrification rate by 2030. For this, different electricity generation systems were compared using the levelized cost of energy (LCOE). This study has been done only for the residential sector of Suriname.

The OnSSET analyses considered a scenario with a rural demand of 2,400 kWh/household/year and an urban demand of 9,600 kWh/household/year (RAGHOEBARSING, 2024). The values for the technologies are presented in Table 2. The capital expenditure (CAPEX) to implement mini grid system with Solar PV, Wind, Diesel generating sets are listed, as well as five types of standalone PV ranging from 20 to 1000 Watt.

Table 2 – Min Grid PV, Wind and hybrid CAPEX

Technology	Capex	Description
Mini grid PV cost	1600 (USD/kW)	PV panel costs including BoS
Mini grid battery cost	1000 (USD/kWh)	Battery capital cost
Mini grid inverter cost	230 (USD/kW)	Inverter
Mini grid diesel generator cost	378 (USD/kW)	Diesel generator capital cost
Mini grid wind cost	2800 (USD/kW)	Wind power capital cost
Standalone PV (under 20W)	9620 (USD/kW)	Type 1 household systems
Standalone PV (21-50W)	8780 (USD/kW)	Type 2 household systems
Standalone PV (51-100 W)	6380 (USD/kW)	Type 3 household systems
Standalone PV (101-1000 W)	4470 (USD/kW)	Type 4 household systems
Standalone PV (over 1 kW)	6950 (USD/kW)	Type 5 household systems

3.2.1 OnSSET results

The map in Figure 5 shows the results of OnSETT with the technology options for grid extension, stand-alone PV and mini grids with hydro, wind, solar and hybrid systems. This map also shows that the dense habitat areas in the interior will be mainly attended by mini-grids with solar and hydropower sources. This area coincides with the Upper Suriname River Resort shown in Figure 4. The result also shows the potential for a small wind power spot in the Galibi resort in the northeast of Suriname. The levelized cost of electricity for every spot is shown in Figure 6.

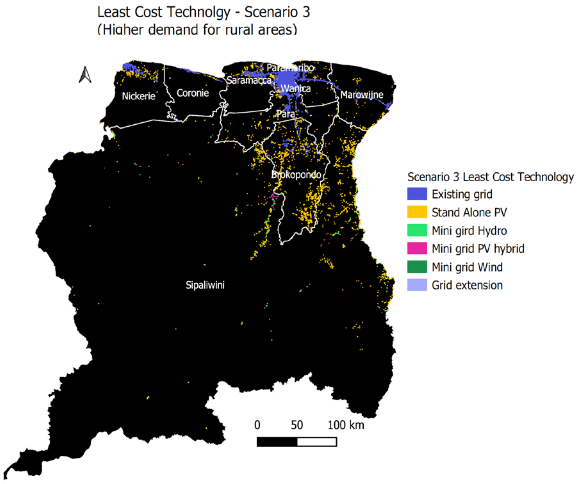

Figure 5 - OnSSET least cost technology option

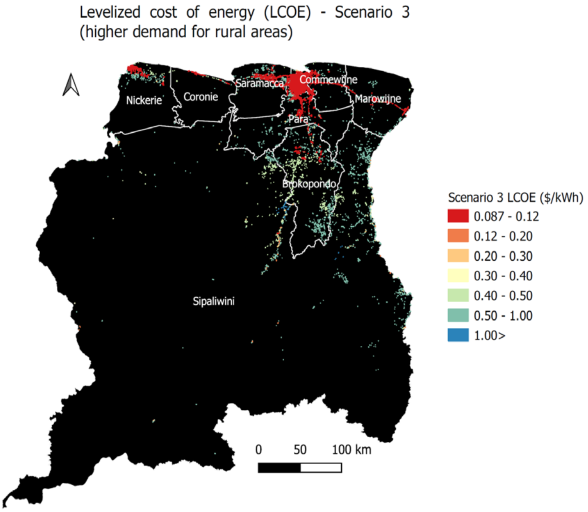

Figure 6 - Estimated LCOE

OnSSET also calculates the total investment cost. To have 100% electrification rate in Suriname by 2030, an investment of USD 360 million needs to be made. Around USD 217 million in investment will be required for the grid extension. Furthermore, 61 MW new capacity will be required to be installed. A total of 117,592 new connections must be made, of which 57,818 must be grid extension. Furthermore, 33,926 will be stand-alone PV systems connections, 20,240 will be mini-grid hydroelectric systems, with 4,708 grid extensions, 734 with hybrid wind and the remaining will be mini-grid PV hybrid systems. For the upper Suriname River resort, the least cost technology that can be used are stand-alone PV systems, mini-grid hydro systems and mini-grid PV hybrid systems with LCOE ranging from USD 0.12/kWh to USD 1.00/kWh depending on the technology used. However, in some villages, the LCOE can be more than USD 1.00/kWh.

4. DISCUSSION

The results of EAE and OnSSER are complementary. While the Energy Access Explorer's multi-criteria analyses appointed priority areas based on a set of criteria, OnSSET calculates the LCOE and necessary investment to achieve the planned goals.

One of the main contributions of the EAE platform is its ability to select priority locations from a set of concrete criteria. This is very important because it permits to use the methodology as a priority selection tool for public policy and decision-making. The use of simple criteria can therefore decrease the influence of politics in these matters. Complementary, OnSSET can then be used to quantify the LCOE and the necessary investment to attend the priority areas. Figure 7 shows the top 20 locations with the highest index calculated by the multicriteria analyses.

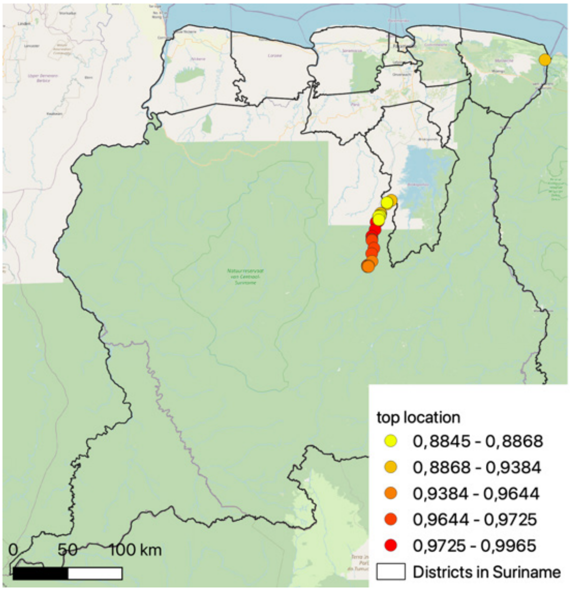

Figure 7 - EAE and OnSSET results

In order to obtain the technological options, LCOE and necessary investment for these top locations, these points were used to create a buffer area with a radius of 2 km, and were superimposed on the OnSSET results. The resulted prioritized area has a population of 14,579 inhabitants that will be attended with 13,348 new connections with solar PV, hydropower and wind power mini grids systems as well as standalone home solar PV systems. The total installed capacity is 9 MW, demanding investment of USD 48 million.

However EAE and OnSSET have some limitations due to the specific characteristics of the Amazon region. It was noted that the population density dataset input layer was one of the most sensitive layers of the model. This is due to the spatial characteristics of the population density model used. It seems that the model does not take into account the specific characteristics of the occupation pattern of the Amazonian settlements. The model gives a population density of average inhabitants per square kilometer, but that does not take into account how the people occupy this area.

The area occupied by the tribal and indigenous inhabitants is relatively widespread, as they need this area for their shifting cultivation agriculture activities and other forest extractivist economic activities, but they have their houses close to each other in the villages and settlements. Therefore it is necessary to implement a clustering algorithm to adjust the demographic population model around the villages and settlements. It is necessary to “tropicalize” the model. Another point of improvement is the availability of more precise data on renewable energy potentials, especially of potential micro & small hydropower sites, as well as stocks of biomass for energy production.

5. CONCLUSION

It has been shown that the Energy Access Explorer (EAE) and OnSSET succeeded in identifying and mapping villages and settlements without access to regular electricity services and, through a spatial multi-criteria analysis, prioritized potential locations and technologies for the rural electrification of Suriname. The EAE methodology indicated 20 priority sites with a population of 14,579 inhabitants. With OnSSET is was possible to calculate the LCOE of each new connection, the least cost technological option, the total new installed capacity and necessary investment for the whole country aiming a 100% electrification rate by the year of 2030. By using both methodology it is possible to select pritority areas of the country based on a set of conditions and quantify the necessary investment and action for these selected areas.

The combination of EAE and OnSSET can be used as a priority selection tool for rural electrification programs and projects as as it gives public policy makers a decision-making tool that is based on a set of objective criteria and quantitave indicators. The adoption of this decision making tool by policy makers can reduces the influence of pessoal or political preferences.

The bottom-up methodology used in these platforms and its implementation for Suriname can be also used for other Amazonian countries as they have almost the same demographic density and occupational patterns.

6. ACKNOWLEDGE

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