

Suriname's Rural Electrification Plan 2030



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Satellite camp "Akani Kampu", Apetina, TTA, 2023.

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Abbreviation	Explanation
ABS	Algemene Statistieken Bureau (General Statistics Bureau)
DEV-MNH	Dienst Elektriciteitsvoorziening (Energy Department of MNH)
DC	District Commissioners
EAS	Energie Autoriteit Suriname (Energy Authority Suriname)
EBS	Energie Bedrijven Suriname (Energy Company Suriname)
ESIA	Environmental and Social Impact Assessment
FPIC	Free, Prior, and Informed Consent
HRBA	Human Rights-Based Approach
IUCN	International Union for Conservation of Nature
KAMPOS	Kwinti, Aluku, Matawai, Paamaka, Okanisi en Saramaccaners - Samenwerkingsverband van Tribale volkeren (Collaboration of Tribal Peoples in Suriname)
MTCT	Ministerie van Transport, Communicatie en Toerisme (Ministry of Transport, Communication and Tourism)
MINOWC	Ministerie van Educatie, Wetenschap, en Cultuur (Ministry of Education, Science and Culture)
MNH	Ministerie van Natuurlijke Hulpbronnen (Ministry of Natural Resources)
MROM	Ministerie van Ruimtelijke Ordening en Milieu (Ministry of Spatial Planning and Environment)
MROS	Ministerie van Regionale Ontwikkeling en Sport (Ministry of Regional Development and Sport)
MZ	Medische Zending (Medical Mission)
PV	Photovoltaic
REM	Reference Electrification Model
SBB	Stichting Bosbeheer en Bostoezicht (Foundation for Forest Management and Production Control)
SHS	Solar Home Systems
TAS	Telecommunicatie Autoriteit Suriname (Telecommunication Authority Suriname)
VIDS	Vereniging Inheemse Dorpshoofden Suriname (Association for indigenous Village Leaders in Suriname)
VSG	Vereniging van Saramaccaanse Gezagsdragers (Association of Saamaka Authorities)



1. Introduction

The present report makes part of the formulation of the Rural Electrification Plan (REP) for Suriname to support the country's efforts to achieve universal energy access by 2030.

This deliverable aims to display the results of the least cost rural electrification plan, going from the description on the data gathered and processed (geospatial, technical and financial data) to feed into the Reference Electrification Model (REM) and planning on the most convenient alternative (grid extension, mini grids, and/or individual solar systems) to electrify the non-electrified users. Additionally, from the base scenario of results, a sensitivity analysis is performed to analyze the robustness of the solution to different changes in the values of the key input parameters.

The report is organized as follows: a briefly explanation of the optimization methodology is described, a characterization of the input data is shown, then it is presented an outline of the results for the base scenario, and from this scenario other sensitivity scenarios are modeled.

The data described in this report will feed the next steps of the georeferenced least-cost rural electrification plan, i.e., developing a methodology and tool for tracking the progress of energy access projects and preparing a financial analysis for their execution.

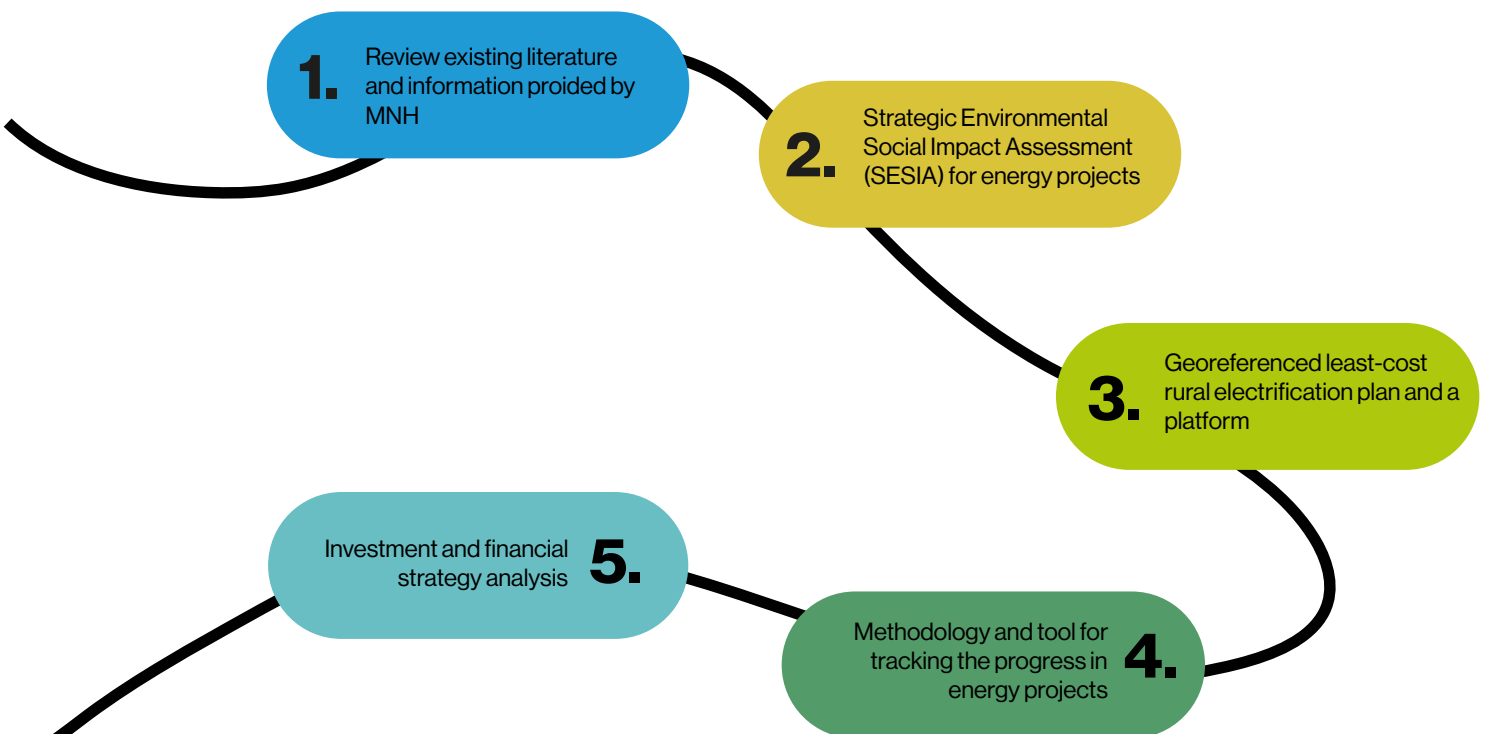


Figure 1. Processes to achieve the georeferenced least-cost rural electrification plan

2. Methodology

The planning methodology is based on a detailed optimization model, the Rural Electrification Model (REM). The model allows for the development of a comprehensive electrification process, including a computational model, decisions and analyses of experts and decision-makers, to achieve universal electrification at the lowest possible cost, and coordinated with other policy and emission

reduction objectives. The results presented in this report are derived from the technical modeling process, after a detailed technical consultation, following stakeholder meetings and extensive data collection.

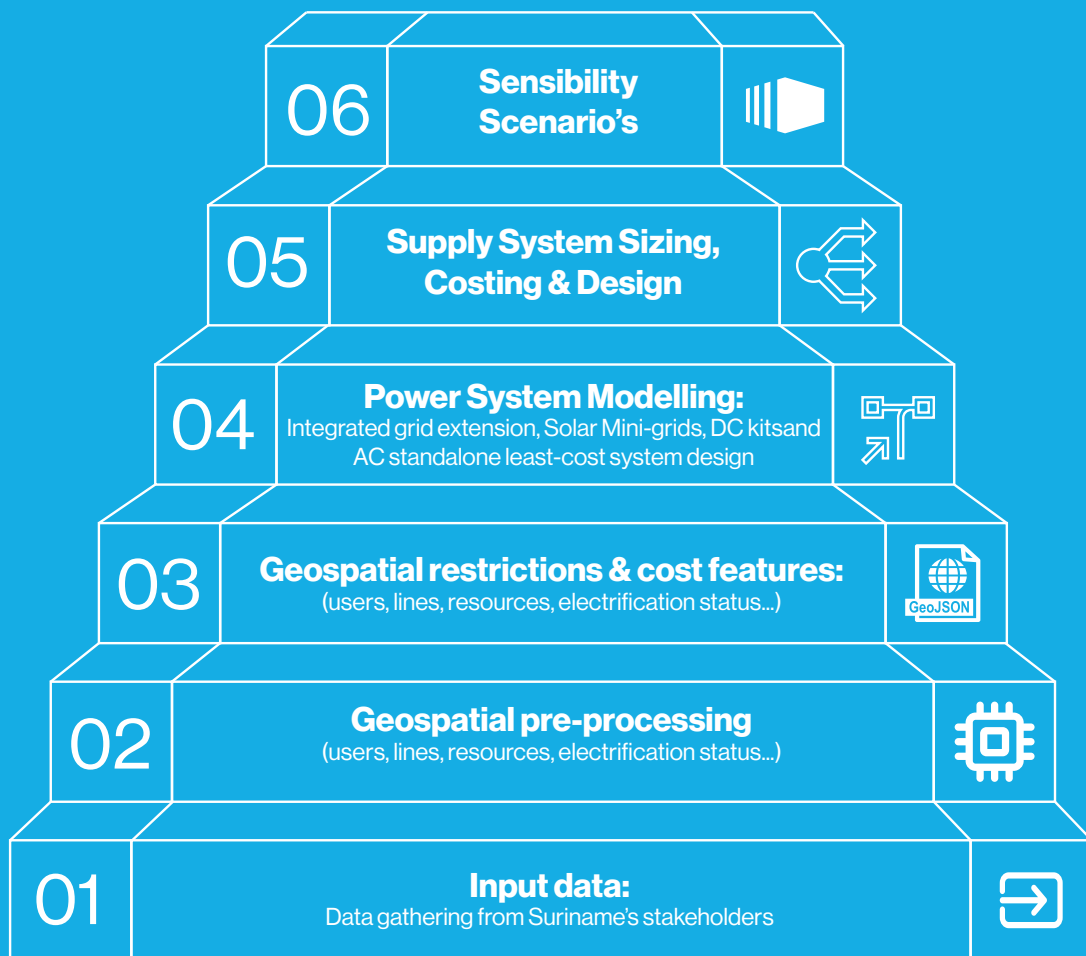


Figure 2. Procedure

The results show a very high level of spatial granularity at the level of individual consumer, and calculations of distribution grid for mini-grids and grid extensions.

3. Input data

The Team has gathered an exhaustive list of required information to execute the rural electrification plan and has contacted different stakeholders to gather as much data as possible.

REM model requires a large amount of information to evaluate the least-cost electrification solution for Suriname.

Specifically, the results provided by REM are based on a combination of geospatially distributed local data, such as customer locations and their individual characteristics such as the hourly demand curve, energy resources, GIS layouts of the existing grid, topographic features, concession or administrative boundaries, grid-related equipment data and the catalog of generation components, and user preferences, including calculated assumptions and strategic decision making.



Data room	Stakeholder contacted
Population	
Latest Census Data	ABS
District Commissioners lists (Sipaliwini)	District Commissioners, MNH
Socio-economic villages characterization	MROS
Demand	
Residential and commercial customer types and demand	TTA, EBS
Energy demand growth	TTA, EBS, MNH
Schools	MINOWC
Health centers	MZ, Ministry of Health
Telecommunications towers	MTCT, TAS, Telesur, Digicel
Population growth	ABS, ROM, CBB
Rural Electrification	
Data Related to un-electrified villages	MNH-DEV, DC
Electrified villages with limited service with diesel generator	MNH-DEV
Electrified villages with solar PV mini grid	MNH-DEV, EBS
Electrified villages through PowerChina project	MNH-DEV
Planned communities to be electrified (PowerChina, India Credit Line, other initiatives)	MNH-DEV
Grid expansion and electrification plan from EBS	EBS
Demand – Geospatial Information	
GPS Location of customers already connected to the grid	EBS
GPS Location of Community & Productive Loads	EBS, TTA
Topographical Information – Geospatial Information	
Water bodies	SBB
Forbidden and protected Areas	SBB
Topography Layer of Suriname	SBB
Satellite imagery	
Night satellite images of Suriname	TTA
Satellite images of Suriname rural communities	TTA
QGIS maps	TTA
Georeferenced maps of communities	TTA
Grid Layout and Area of Activity - Geospatial Information	
Concession boundaries	EBS
GPS layout of HV grid	EBS
GPS layout of the MV grid, including locations of the MV/LV transformers	EBS
GPS layout of the LV grid	EBS
Grid Catalog (MV/LV and grid-compatible mini-grids)	
MV/LV Transformers - cost and technical characteristics	EBS
MV Lines - cost and technical characteristics	EBS
LV Lines - cost and technical characteristics	EBS
Other Grid Parameters	

Table 1. Stakeholders involved in data gathering phase.

Data room	Stakeholder contacted
MV voltage level	EBS
LV voltage level	EBS
Energy cost at MV level	EBS
Energy cost at BV level	EBS
Lifespan of distribution assets	EBS
Installation cost per grid connection	EBS
Grid Reliability (SAIDI/SAIFI)	EBS / EAS
Discount Rate for grid distribution business	EBS
LV and MV code for rural areas	EBS
Costs and technical specifications	
CAPEX costs for diesel generators	TTA, MNH
Diesel costs with and without subsidy	MNH, TTA
CAPEX Costs for Solar PV mini grids (from Power China, IADB)	MNH-DEV, TTA
CAPEX costs typical solar kits available in the country	TTA, local installers
OPEX costs for Solar PV mini grids	TTA

Table 1. Stakeholders involved in data gathering phase.



3.1. Georeferenced processing and restrictions

3.1.1. Geography

Figure 3 shows the administrative boundaries of districts and resorts in Suriname. Suriname has 10 districts which are divided into a total of 63 resorts. Most of the non-electrified population in Suriname are situated in the district of Sipaliwini.

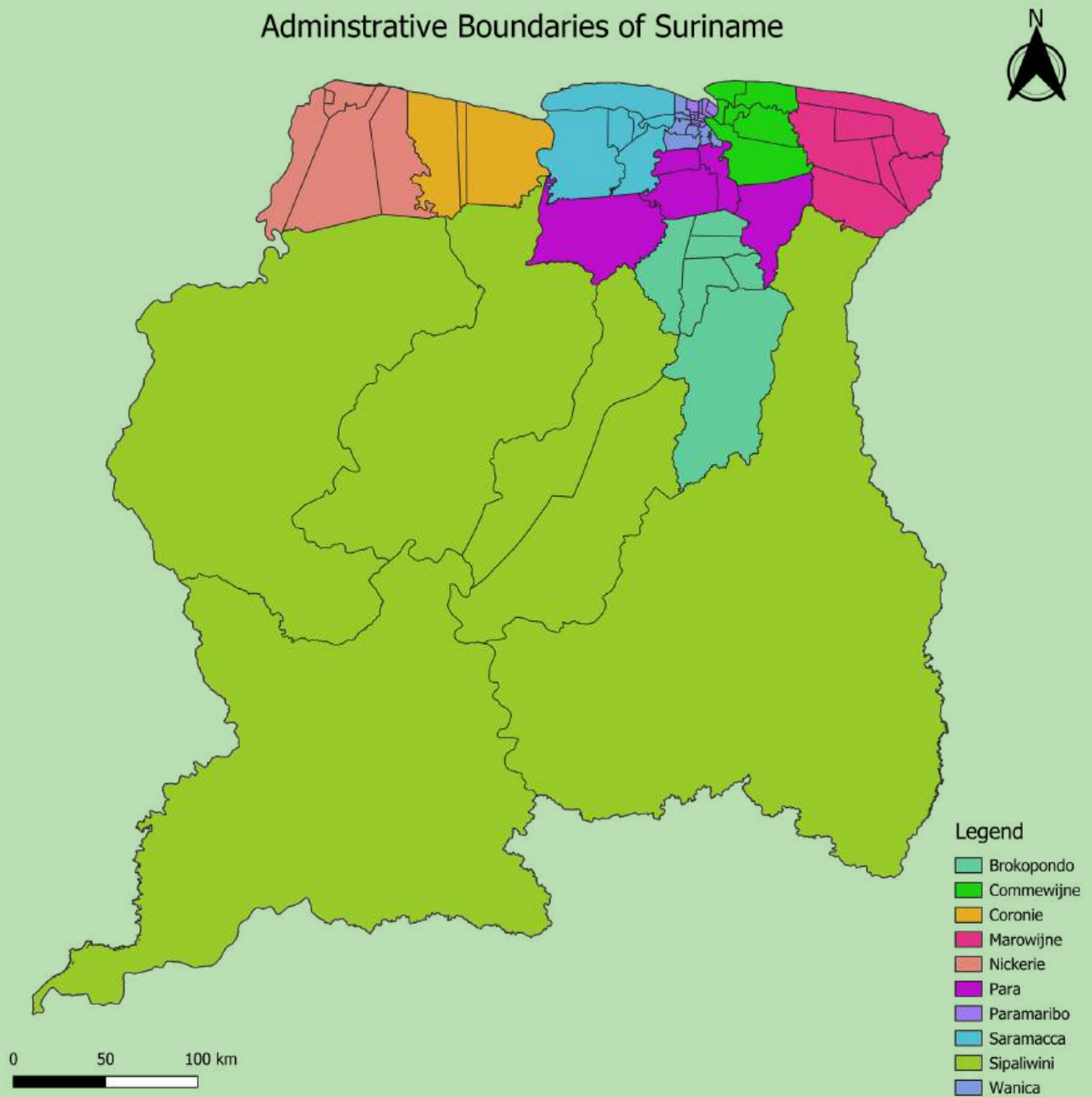


Figure 3. Suriname's administrative distribution.

3.1.2. Topography

Suriname's topography, as shown in **Figure 4**, illustrate the shape and elevation of surface features using colored pixels.

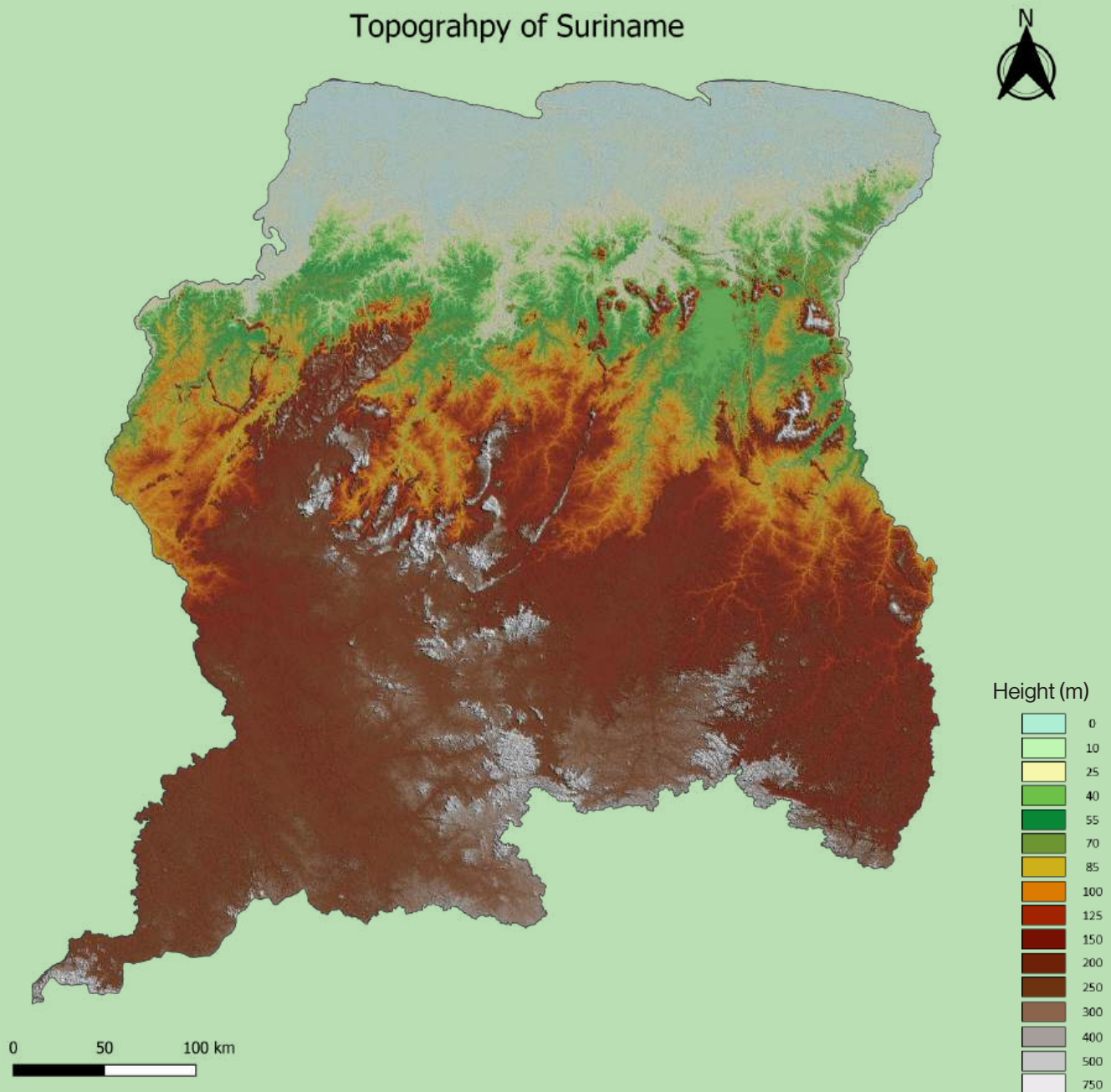


Figure 4. Suriname's topography.

3.1.3. Natural protected areas

Figure 5 shows the protected areas in Suriname. These protected areas are categorized as either nature park (Brownsberg), national reserve (Boven-Coesewijne, Brinckheuvel in Brokondo, Central-Suriname, Copi, Coppenamemonding, Galibi, Hertentrits, Peruvia, Sipaliwini Savana, Wanekreek and Wia-Wia), private protected area (Peperpot), multi-use managed area (Bigi Pan, Noord-Commewijne-Marowijne, Noord-Coronie en Noord-Saramacca) or as proposed nature reserve (Nani and Kaboeriekreek) or forest reserve (Mac Clemen and Snake Kreek).

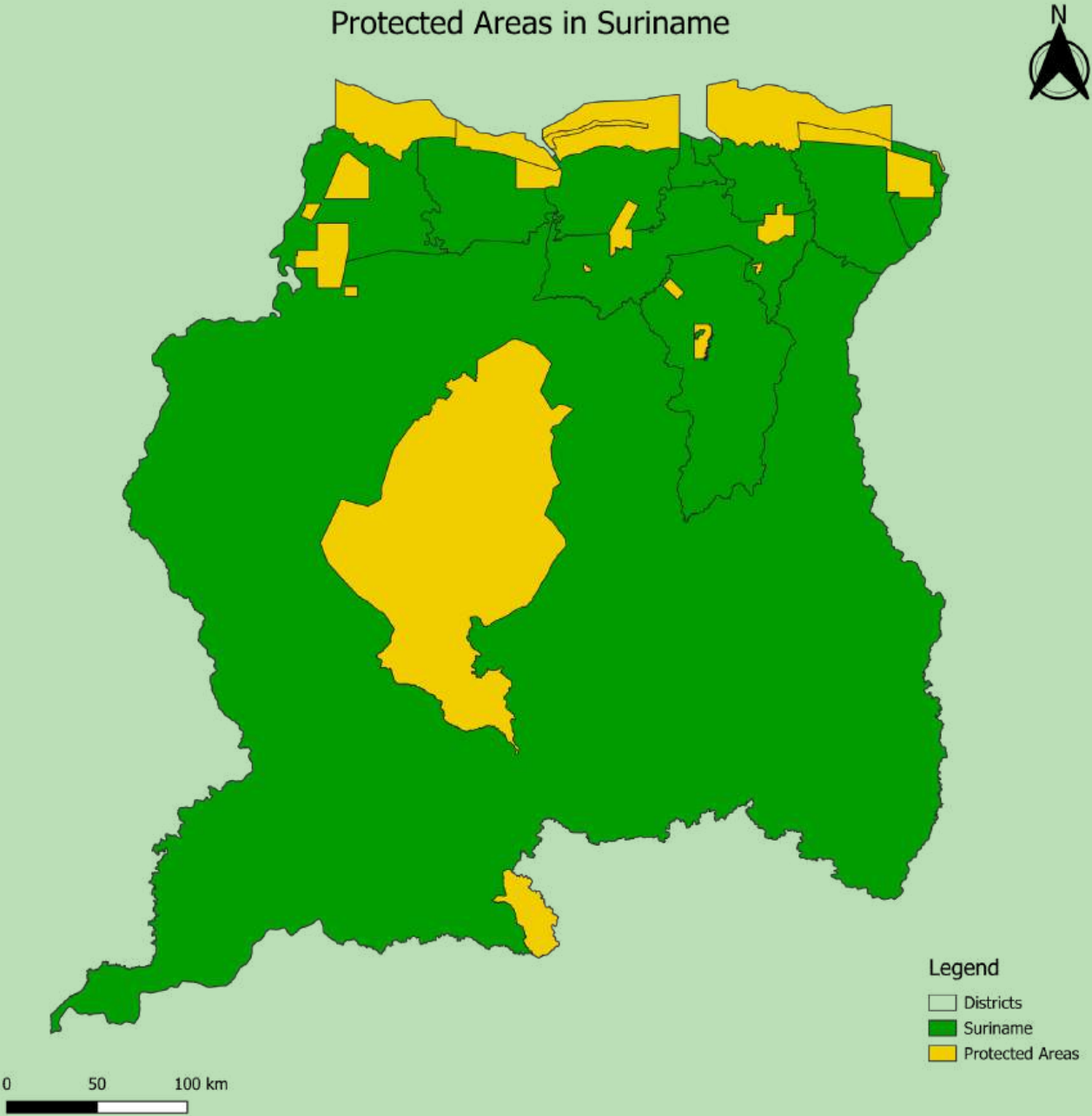


Figure 5. Suriname’s protected areas.

The hydrography in **Figure 6**, shows the prominent waterbodies in Suriname, this includes the van Blommensteinmeer, Marowijneriver, Surinameriver, Coppeneriver and Corentyneriver.

Green indicates forested areas – either pristine, secondary or tertiary. Aside from prominent waterbodies and forested areas, non-forest areas are also projected.

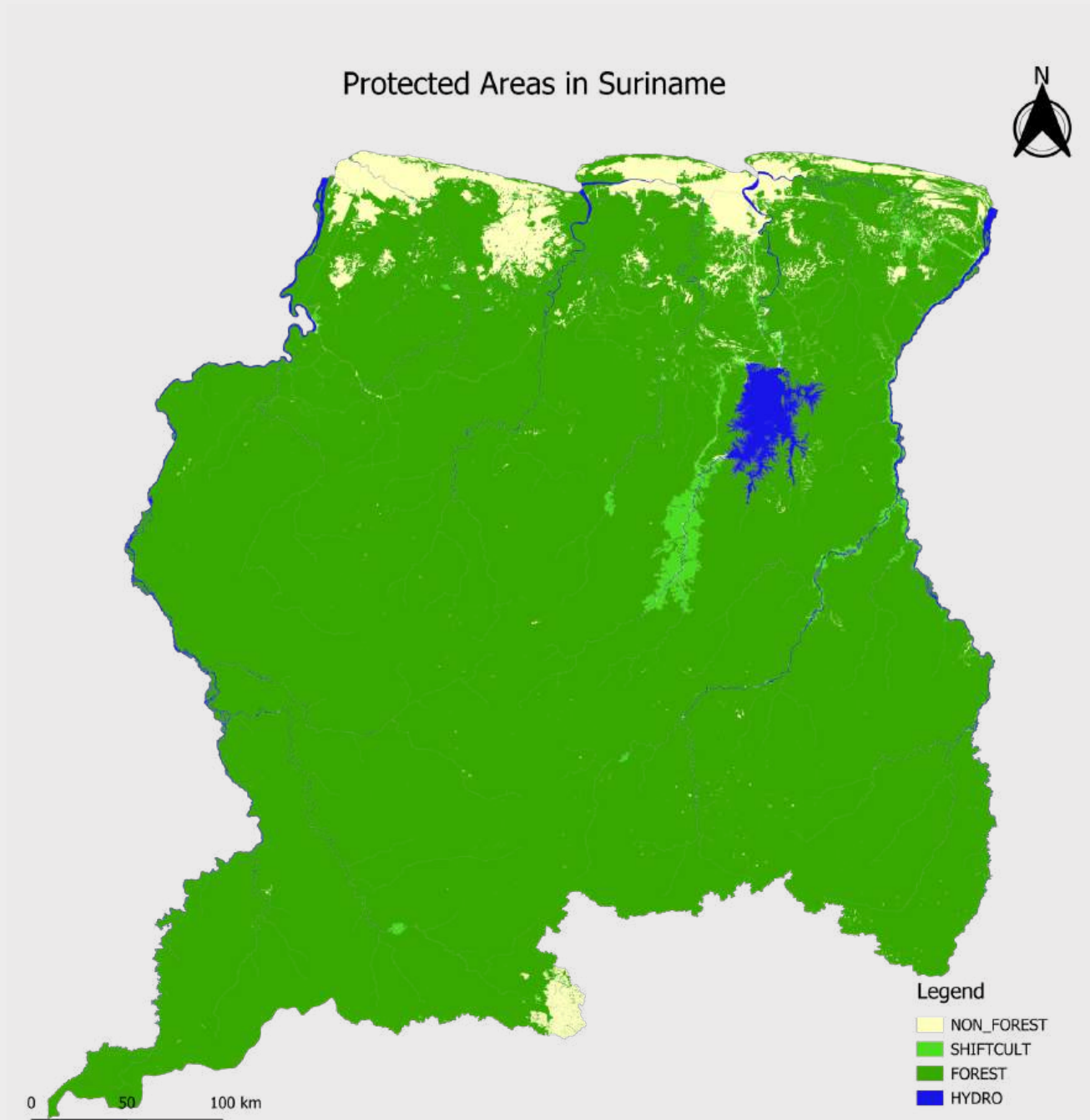


Figure 6. Suriname's hydrography, forest, and non-forest areas.

3.1.4. Non-electrified and with limited access to energy users

The Team has gathered as much data as possible on the villages in rural areas, to understand which areas are still not being served, which communities have a limited access with independent diesel gensets, and what are the different levels of access.

A demographic characterization of the communities was also necessary to determine the number of inhabitants per household and per family and understand the distribution of living spaces. It is common to find more than one household within one family having shared common spaces like the kitchen. For the current assessment the assumption has been made that each household is considered as a potential individual customer, rather than by family group. On average, there are around 3 to 5 people per household depending on the wealthiness level of the village.

Households are comprised of a typical nuclear family with only two generations mainly. Family groups are comprised of several households including three or more generations and more than one nuclear family.

Domain	Population
Urban	406,800
Rural	122,300
Hinterland	87,400
Total	616,500

Table 2. Estimated Mid-Year Population at Urban, Rural and Hinterland domain (2021). ABS Census.

Some of the houses are composed by 2 or 3 separate buildings (in particular in indigenous communities), these parameters are relevant for the final energy demand analysis and are decisive when defining the number of users to include in the least-cost rural electrification plan.

To define Suriname's non-electrified or with limited access population in the rural areas in 2023, the team conducted a thorough data collection from District Commissioners (DC), SBB, and MNH-DEV. This data was cross-checked with satellite imagery to make sure all settlements and camps were mapped out, and the population and number of households in each settlement and camp was identified.

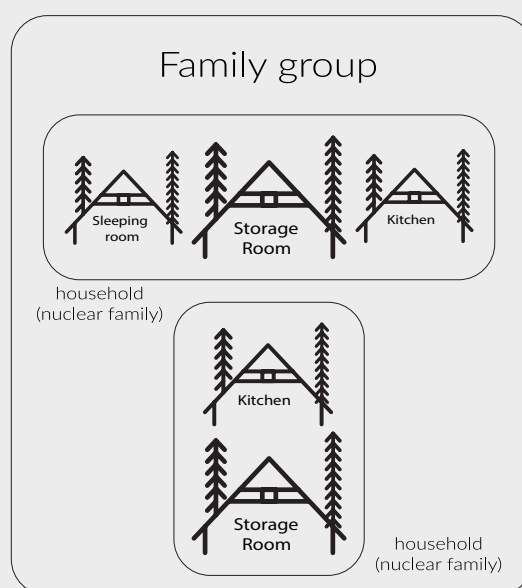


Figure 7. Suriname's households composition (rural communities).

Table 3 shows the data sources examined to identify buildings, settlements, villages or clusters of users electrified and non-electrified.

Data Source	Settlements	Buildings	Households/Users
DEV - MNH	135 villages with diesel generator	406,800	27,994 households
SBB	280 settlements, 124 camps	122,300	
DC's	187 settlements		20,698 users
Google Hybrid	234 settlements	303,469 – 328,416	
OSM	213 settlements	260,433 – 279,928	
Microsoft1		18,822 – 18,940	

Table 3. Building identification from different databases.

Figure 8 displays the nighttime locations of potential energy consumers (depicted in black), as determined through satellite data sources, specifically the High-Resolution Electricity Access from Microsoft. Meanwhile **Figure 9** provides an overview of the population density in Suriname (High-Resolution Population Density Maps from Meta).

The comparison between different public databases and data from the Government of Suriname to identify users per village / settlement / clusters non-electrified was essential, since some data bases contain partial dat

Figure 10 shows two examples of buildings detected by public satellite data sources. Each building does not correspond necessarily to one user since one household might own more than one building. A final selection of buildings was made to avoid oversizing non-electrified population hence the final energy solutions.

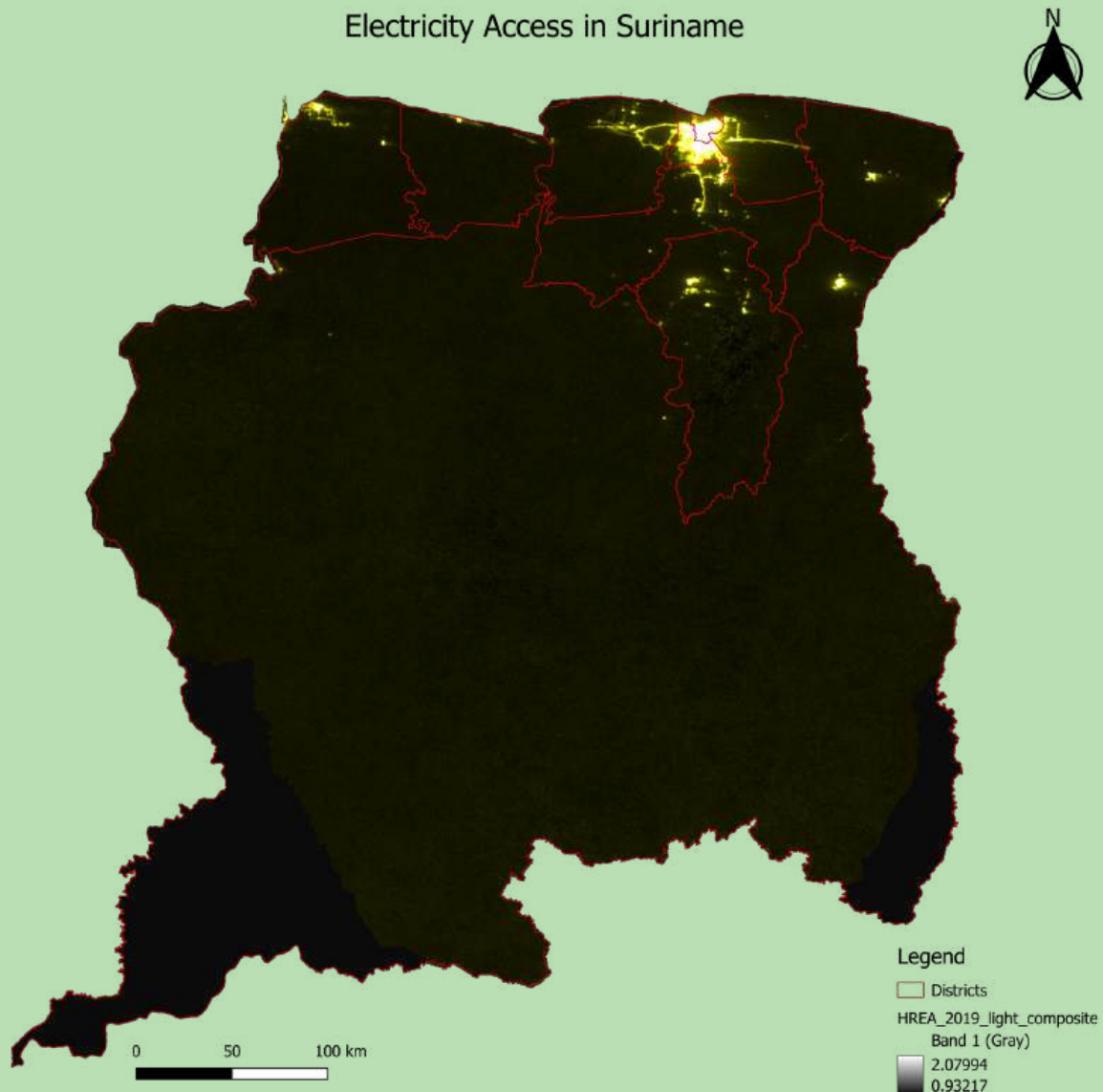


Figure 8. Suriname's electricity access identified through satellite data sources.

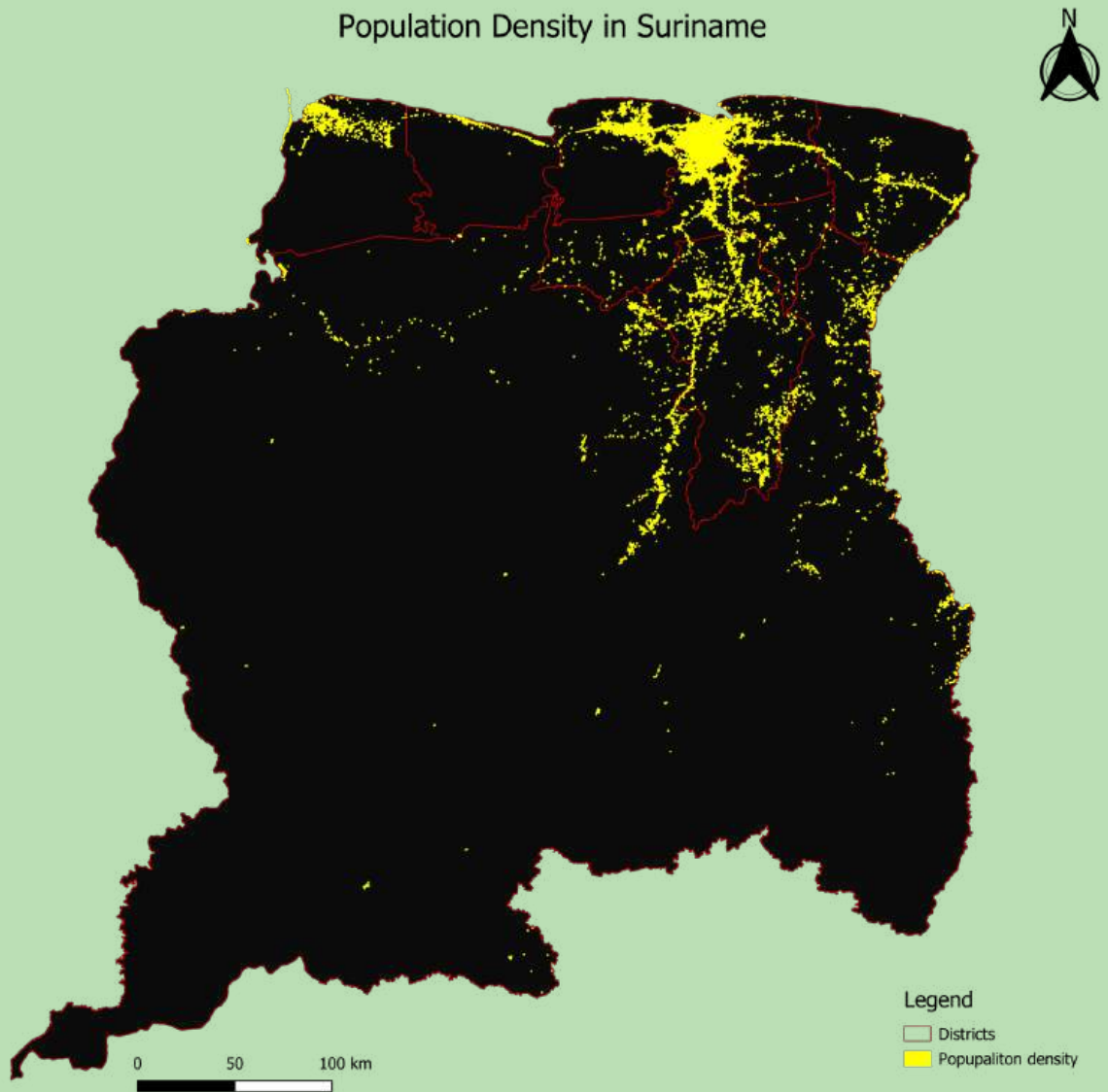


Figure 9. Suriname's population density identified through satellite data sources.



Figure 10. Example of two villages identified buildings (Pusugrunu and Apetina).

Figure 11 illustrates the diagram representing non-electrified and with limited access users that have been identified. The count of identified communities, deviates from the figures presented in Table 3. This disparity arises from the exclusion of already electrified communities in the coastal (urbanized) area's, a refinement informed by the GIS data obtained from EBS.

There is a total of 235 communities without or with limited access to electricity. Of these 235 communities, 198 were identified in the map, meanwhile 37 them have not yet been precisely located. Nevertheless, these 37 communities that were not identifiable in the map represent only 0.5% of the total population to be electrified. It is presumed that these locations are small camps of one or two households that are likely nomadic in nature and move from one location to another depending on their economic activity or availability of resources.

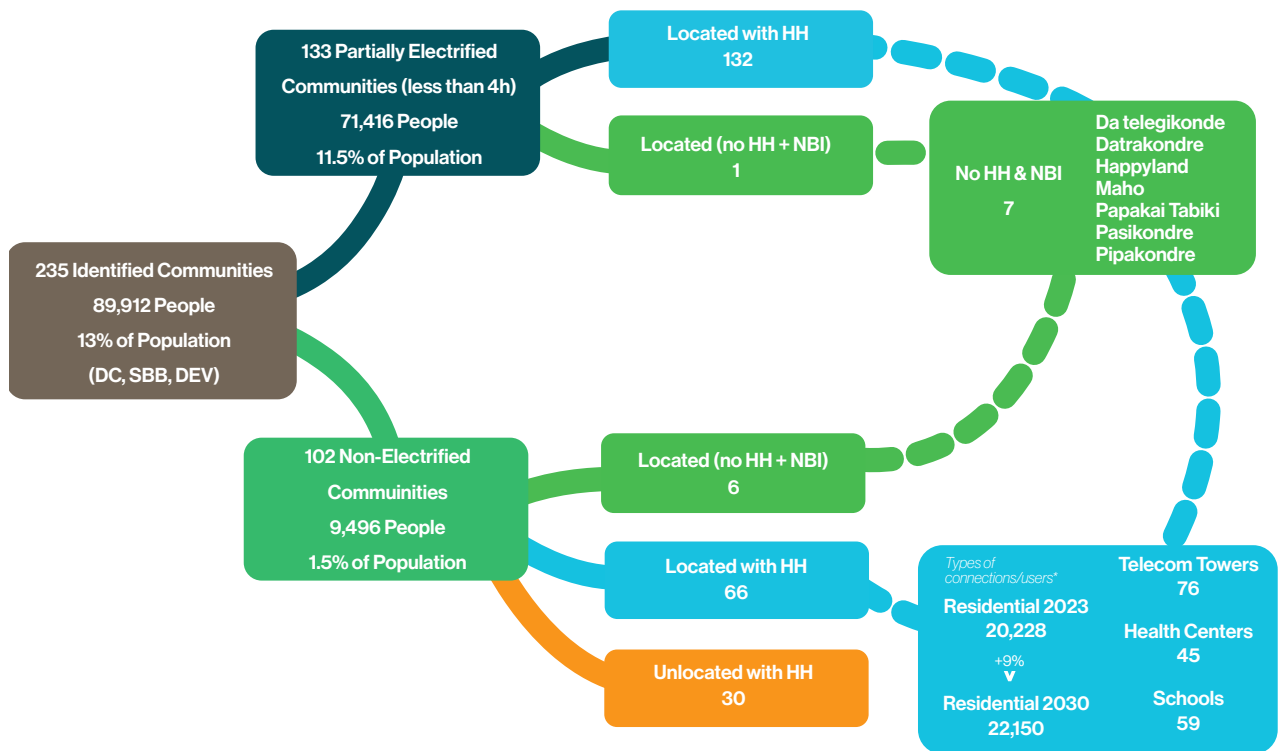


Figure 11. Diagram of identified communities non-electrified or with limited access to electricity user types2.



Figure 12 shows the electrification status of the identified settlements: electrified refers to settlements with energy service from EBS or a mini grids solar PV implemented project (24 hours service). Limited electrification refers to settlements with a diesel generator, which only receive electricity for a few hours per day and depend on the diesel fuel coming from the city. Non- electrified refers to settlements without any type of formal electricity service. For this report the total population to be electrified will be made up of limited electrification and non-electrified users.

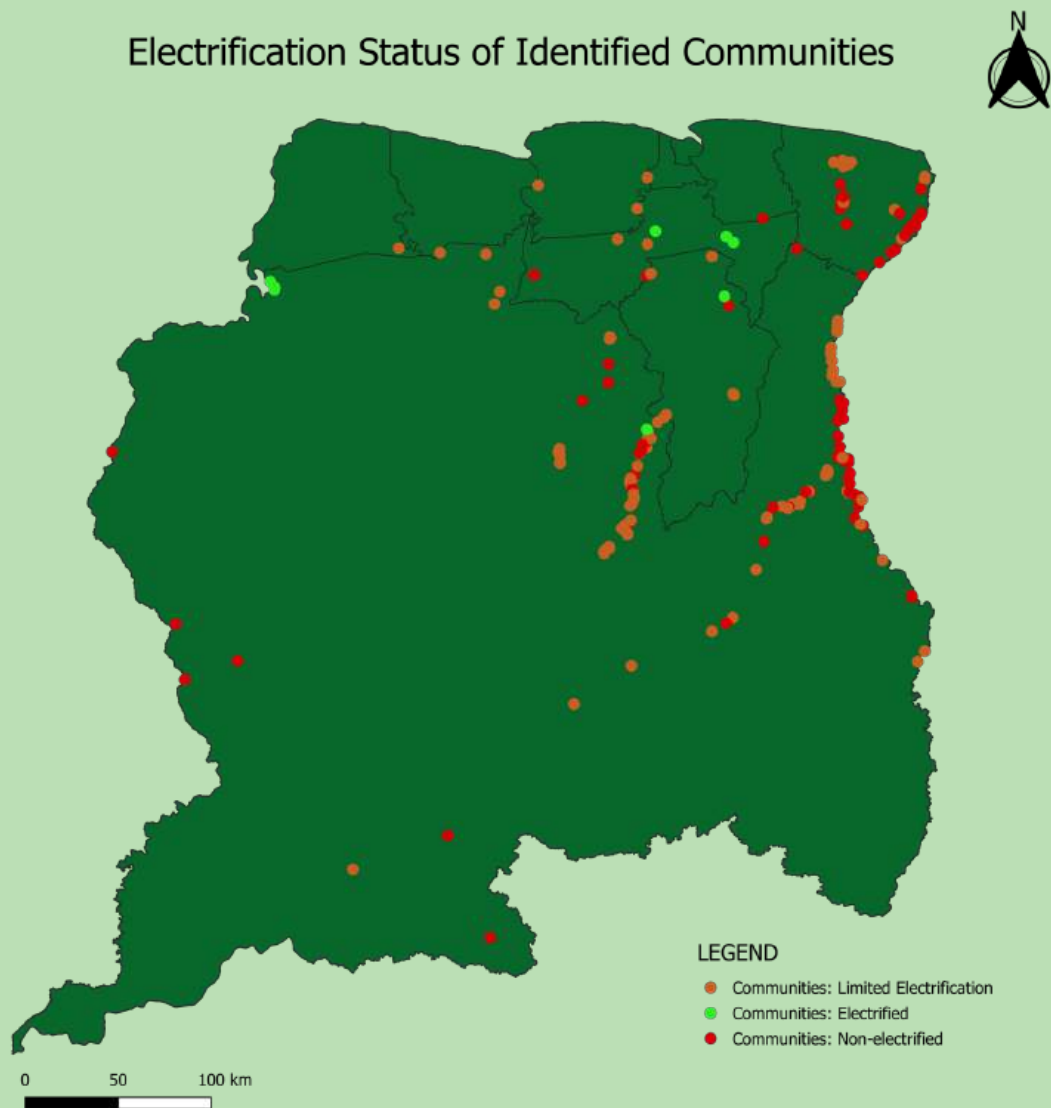


Figure 12. Electrification status of identified settlements.

It is possible that some users on these last group of settlements have electricity from individual solar panels and might be counted as electrified, however, it is not possible to know if the capacity of these equipment is enough to supply their energy needs or the condition of these equipment hence their lifetime. In consequence, it is assumed that the total population in a non-electrified settlement needs a new electrification alternative.



Figure 13 illustrates the location of schools and health centers non-electrified or with limited electrification in Suriname.

The non-electrified population is projected every year until 2030 (6 years according to the period of the rural electrification plan) to define the final energy demand and non-electrified users. Alternative solutions (grid extension, mini grids, SHS) will be proposed by REM model depending on the population density and energy demand.

Rural electrification plan - Formulation of the Rural Electrification Plan for Suriname to support the country's efforts to achieve universal energy access by 2030

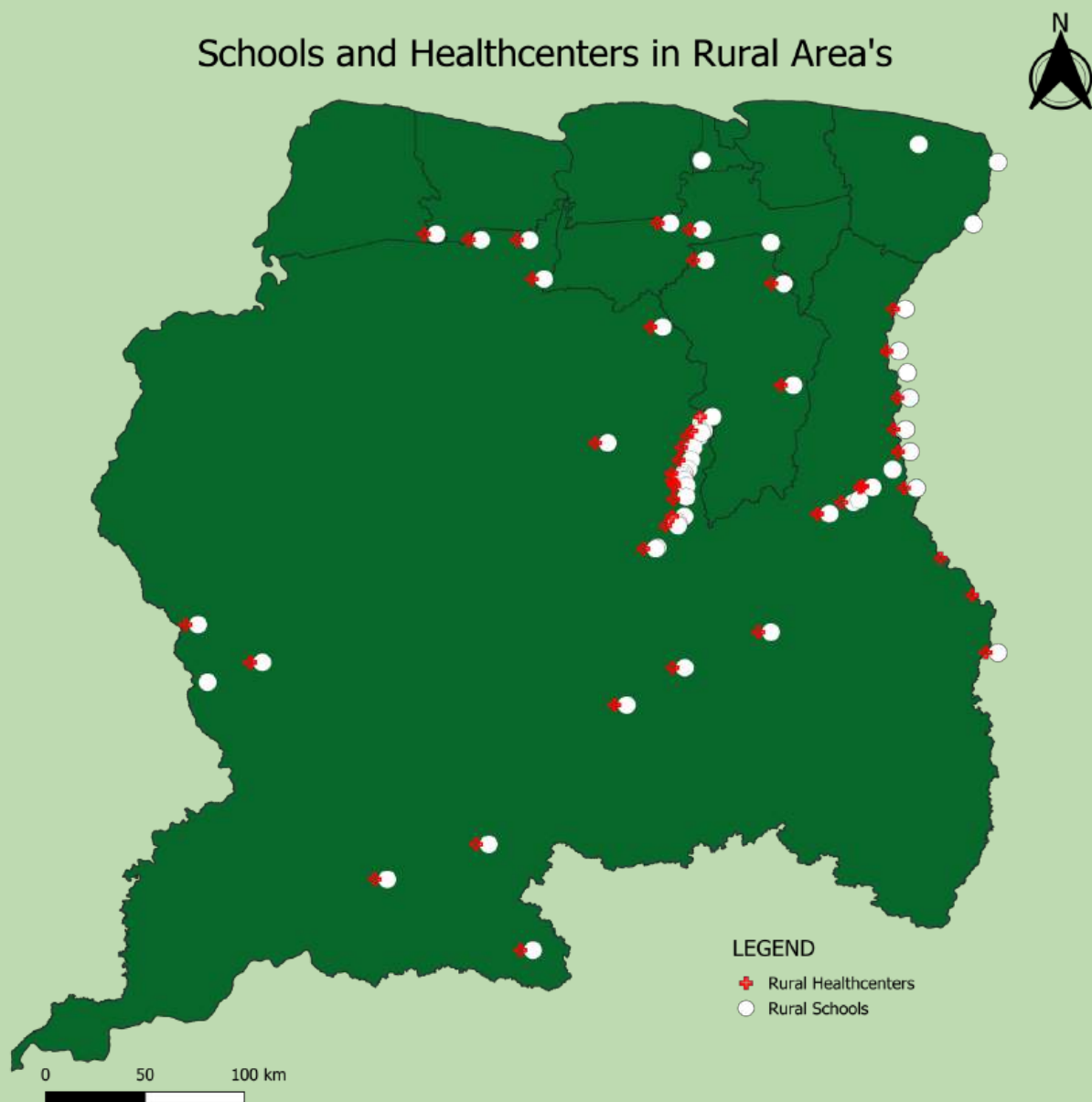


Figure 13. Schools & health centres in rural area's

	Residential users	Percentage
Total population 2023 ³	616,500	100%
Electrified population in 2023	535,588	86.88%
Limited electrification (A)	71,416	11.58%
Non-electrified population in 2023 (B)	9,496	1.54%
Population to be electrified (A + B)	80,912	13.12%
Non-electrified population in 2030	88,600	NA

³It is assumed that 2023 population is the same as ABS 2021 census.

⁴It is assumed that 4 people inhabited per household.

Table 4 . Non-electrified residential users in 2023 and 2030.

According to OLADE, Figure 14 shows that the Caribbean and South American countries with the largest electricity access deficits are Haiti, Bolivia, Guyana, and Suriname



Figure 14. Share of population with access in the Caribbean and South American countries (%), OLADE, 2021.

3.1.5. Existing distribution grid

EBS distribution grid (including MV and LV lines and transformers) allows to define the distances from the identified buildings or users to the existing grid. Typically, the traditional method of electrification has been the extension of the distribution grid and is often the most cost-effective solution for access to electricity.

However, the cost of this alternative will increase depending on the location of the non-electrified population, and it might be impossible to extend the grid over protected areas to reach the most distant users. In this case, alternative solutions as mini grids and/or solar individual systems should be more convenient. As seen in **Figure 15**, most of limited electrified, and non-electrified settlements are located far from the distribution grid.

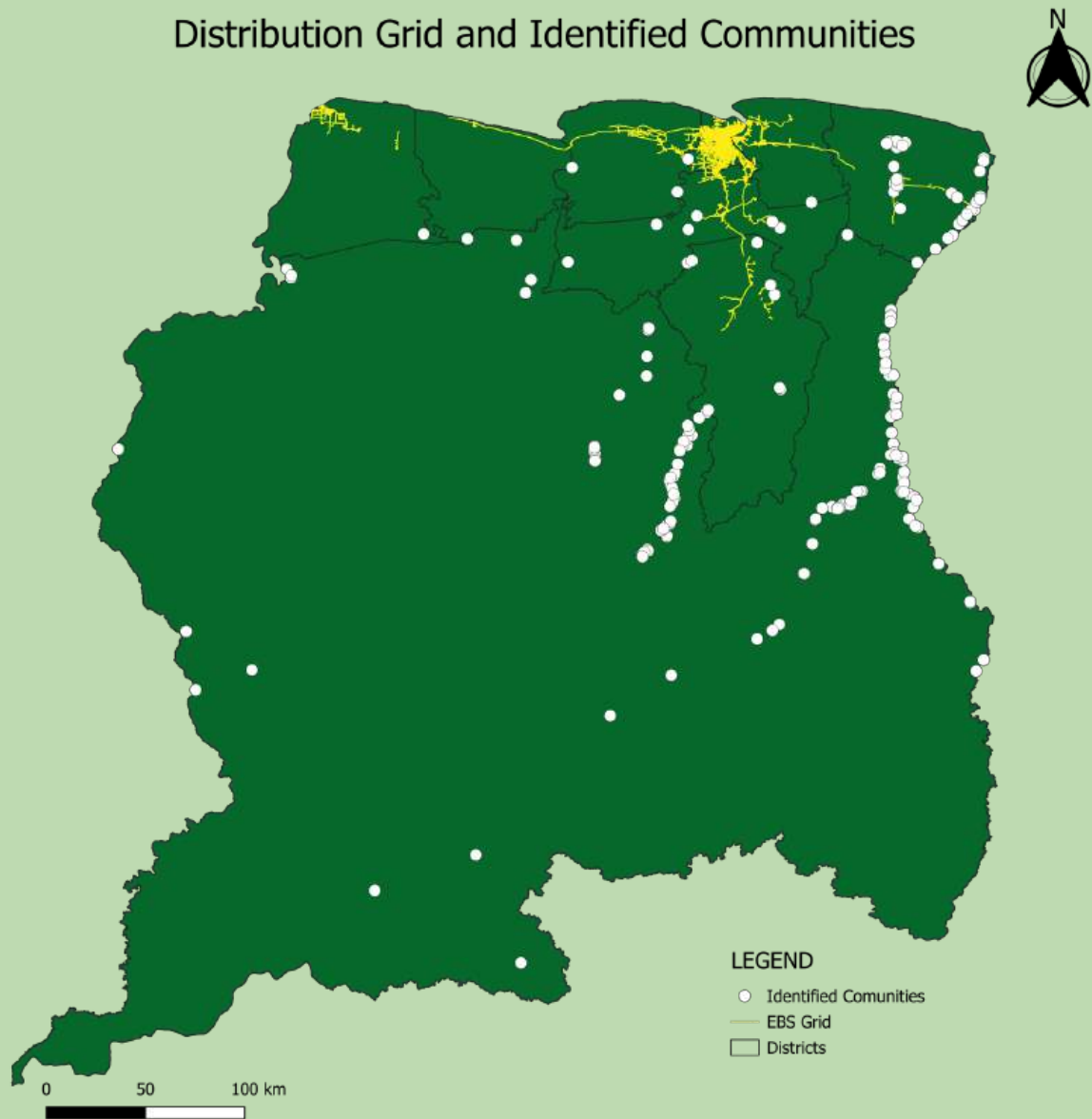


Figure 15. EBS distribution grid and electrified, limited electrified, and non-electrified settlements.

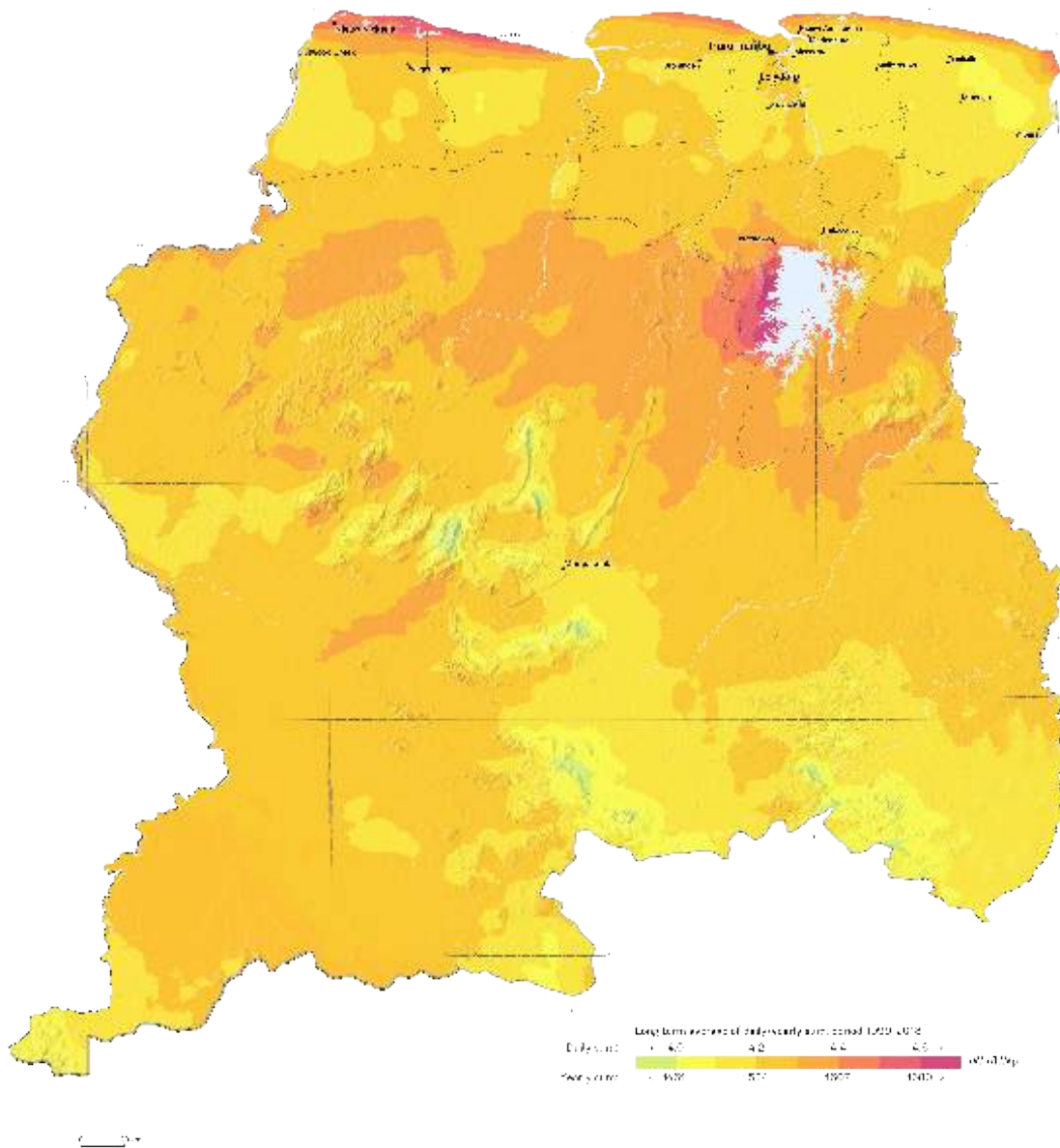
3.2.Primary energy

The availability of different energy resources in a given area is necessary to determine the suitability of different types of generation, in this case, the average solar irradiance in Suriname goes from 5.2 to 6.0 kWh/m²/day and the solar photovoltaic energy potential goes from 4.0 to 4.6 kWh/kWp5.

On the other hand, the cost of diesel is an essential variable to consider when assessing if hybrid alternatives would be included in the analysis. For example, in some communities, diesel transportation is done by aircraft at a very high cost for MNH, e.g., a private Caravan to carry 1,000 kg costs up to 3.780 USD depending on the region. The real cost of fuel might be almost 4-5 USD per liter in the southern villages of the country: pump price for diesel

was 42 SRD/liter (1.13 USD/liter) in December 2023, plus 3.78 USD/liter for transportation totals 4.92 USD/liter.

Considering these fuel costs, the cost of electricity generation in a Southern village can reach up to 2.39 USD/kWh (only for fuel) without considering salaries, overhauls, or other O&M tasks. This is almost 30 times more expensive than the cost of generation in the grid which is around 0.07 USD/kWh (without considering the fixed monthly component of the tariff).



Photovoltaic power potential map Of Suriname

3.3. Geographical regions of analysis

Suriname's rural areas hold very different living conditions for its population compared with urban or coastal areas. The population's growth percentage varies between rural and urban regions as well as the cost of fuel and goods. Moreover, transport costs are higher the farther away the settlement is from the city.

As an attempt for including these differences into the least cost rural electrification analysis, three geographical areas (**Figure 16**) were defined (Urban, Rural – Central & Southeast, Rural – Southwest) to assign different costs of equipment, rates of growth population per region, cost of fuel, and cost of energy not supplied (equivalent to the cost of alternative energy use like candles, kerosene lamps, disposable batteries, etc.).

In this way, for instance, it will be more expensive to install a solar panel in the southwest region than the urban region, and in like manner the costs of operation and maintenance will be also higher in view of the higher transport costs.

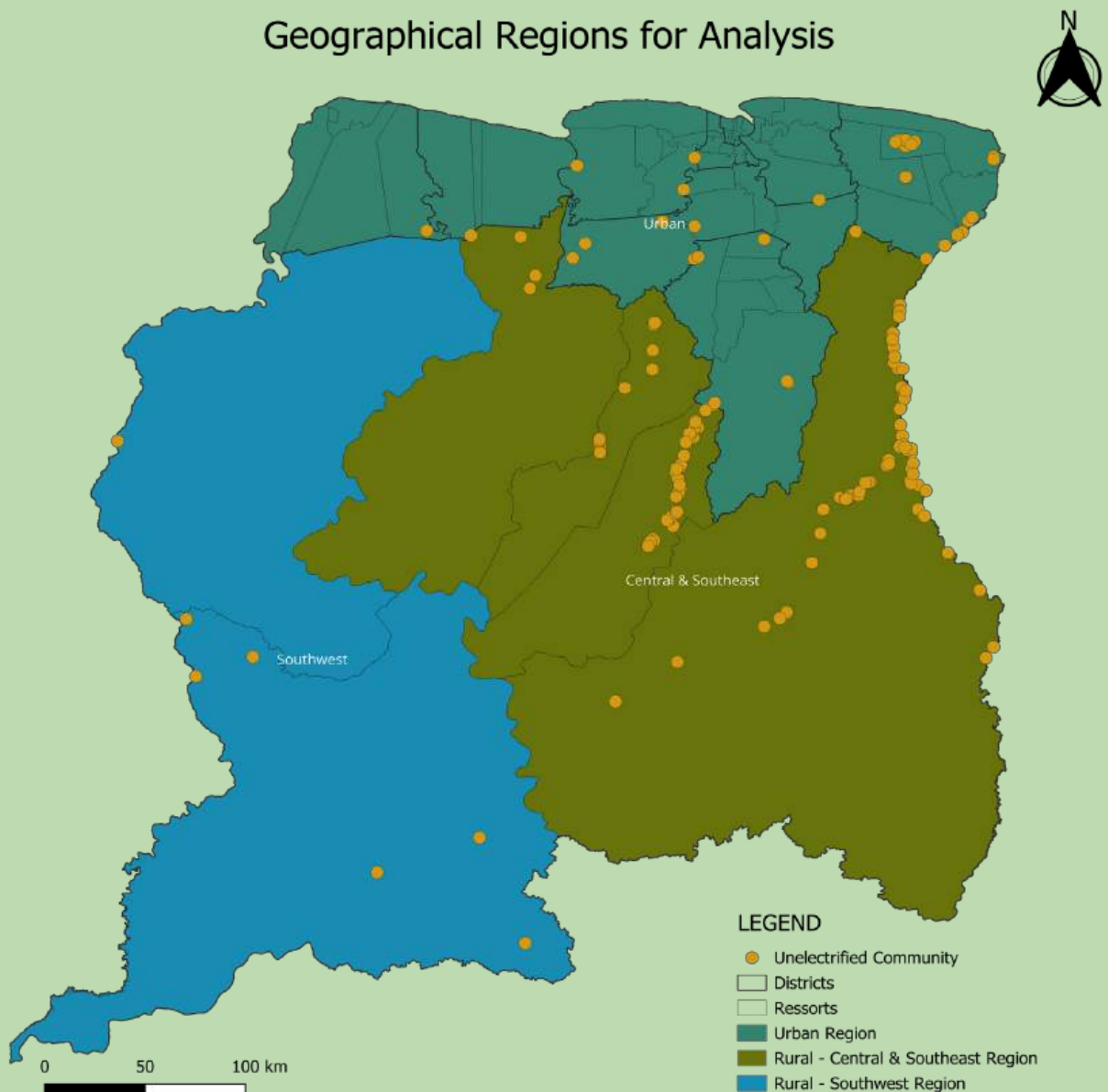


Figure 16. Geographical regions of analysis and non-electrified settlements.

Settlement location	Annual population growth	Diesel approximate cost (USD/lt)	Cost of energy not supplied (\$/kWh)	Transport costs (USD/kg)
Urban	1.1%	1.06	0.55	0.1-1
Rural – Central & Southeast	0.83%	3.47	1.83	3-5
Rural – Southwest	0.83%	4.53	2.39	4-6

Table 5 . Parameters for geographical regions of analysis.

3.4. Demand profile

Designing electrification solutions for non-electrified users, requires an estimate of how much electricity each user could consume if it had access to electricity. Since REM will attempt to meet the specified demand at the lowest techno-economic cost, more detail on the demand at each individual load point is likely to influence the results. In Suriname, there is no minimum regulated energy consumption per user. A socio-economic description of the villages to understand the energy demand is being extracted from previous experiences in the Upper and South Suriname region and data sources described in Section 3.

Together with MNH it has been agreed to assign the same estimated energy consumption per user independently of their geographical location. Table 6 shows the average energy consumption for type of user defined according to the consultant experience when estimating energy demand profiles for indigenous and maroon communities in the rural areas, and stakeholder's consultations such as EBS historical records.

Type of user	Demand (kWh/day) (average)	Demand (kWh/year) (average)
Residential	2.9	1,026
School	3.9	1,386
Health center	9.9	3,564
Business	5.3	1,908
Telecom	45.0	16,200
Residential (city)	5 - 10	1,800 – 3,600

Table 6 . Average energy consumption for different types of users.



The base case scenario will not consider energy demand growth per non-electrified user for the next 6 years (2024-2030) only population growth. It is assumed that the current energy demand of a non-electrified user will remain the same, and it might only grow the next years after the user is served

with electricity. An hourly energy profile per type of user has been defined. The following figures shows different energy demand profiles for different type of users:

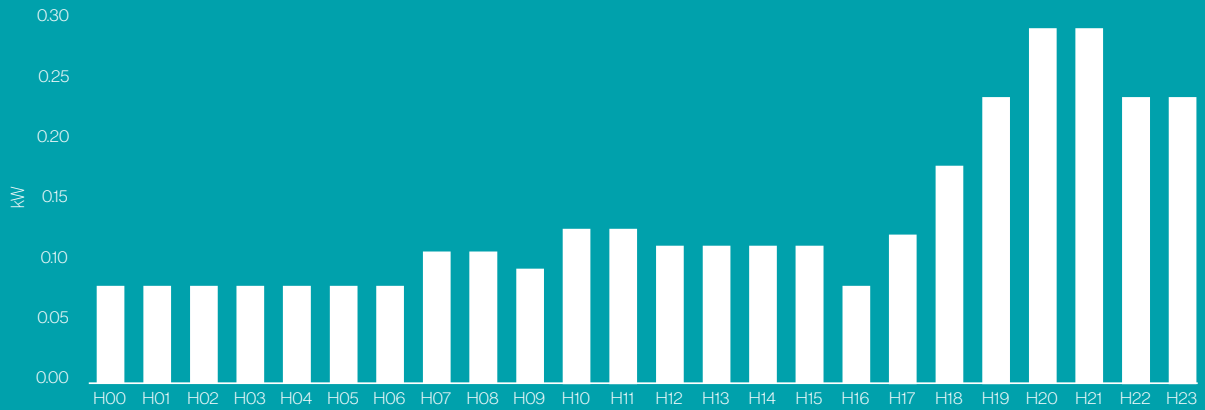


Figure 17. Energy demand profile of a residential non-electrified user.

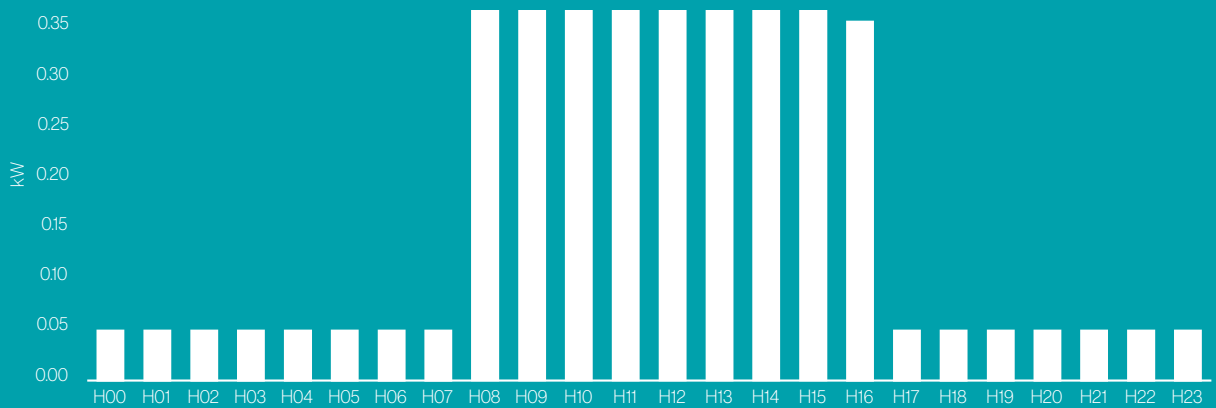


Figure 18. Energy demand profile of a school in a non-electrified settlement.

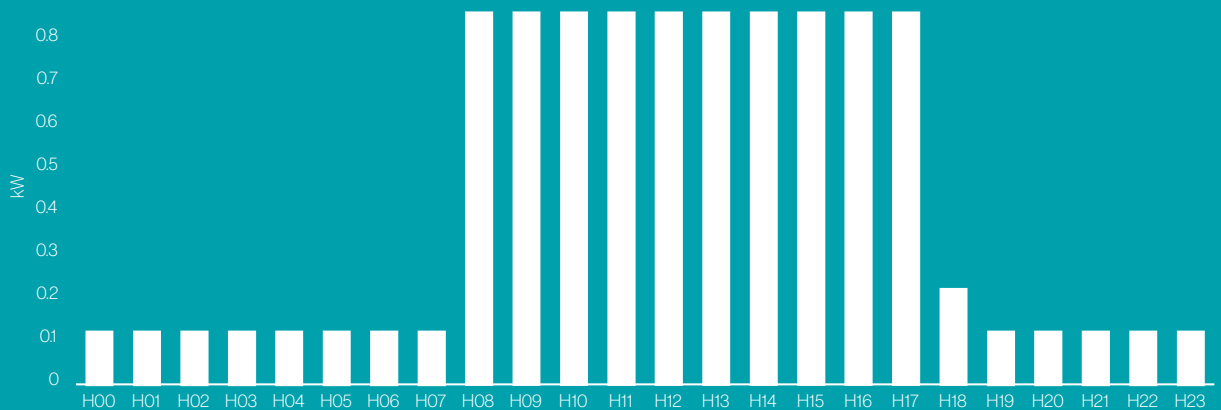


Figure 19. Energy demand profile of a health center in a non-electrified settlement.

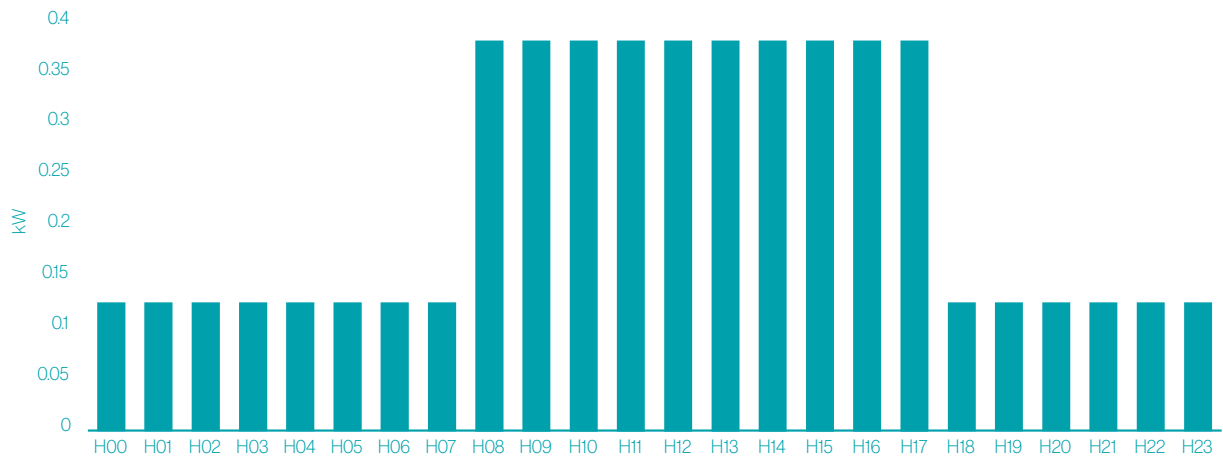


Figure 20. Energy demand profile of a business in a non-electrified settlement.

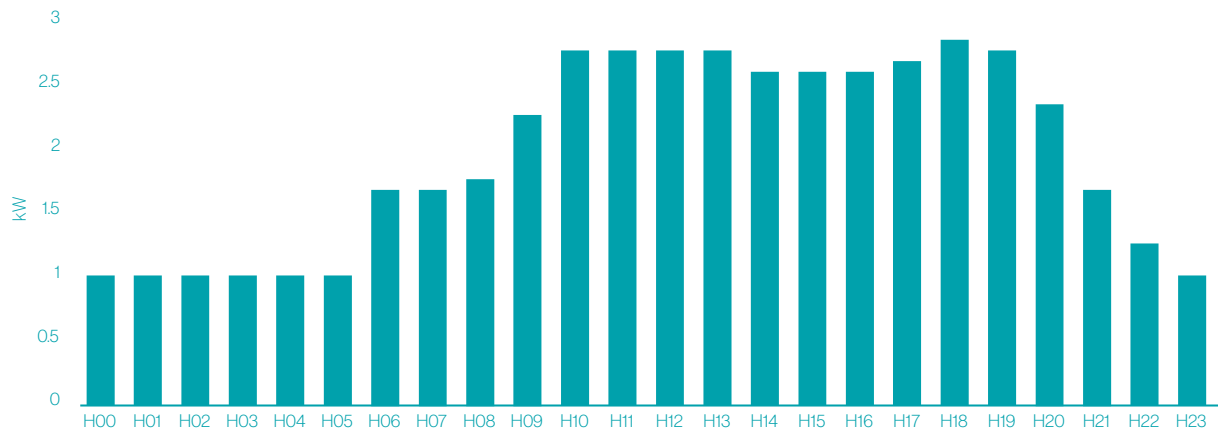


Figure 21. Energy demand profile of a telecom tower in a non-electrified settlement.



4. Base case scenario results

Figure 22 shows the selected electrification alternative for each non-electrified or partially electrified community identified. Some of them have a combination of mini grid and isolated individual systems depending on the users dispersion from the main population cluster.



Figure 22. Electrification mode per community.

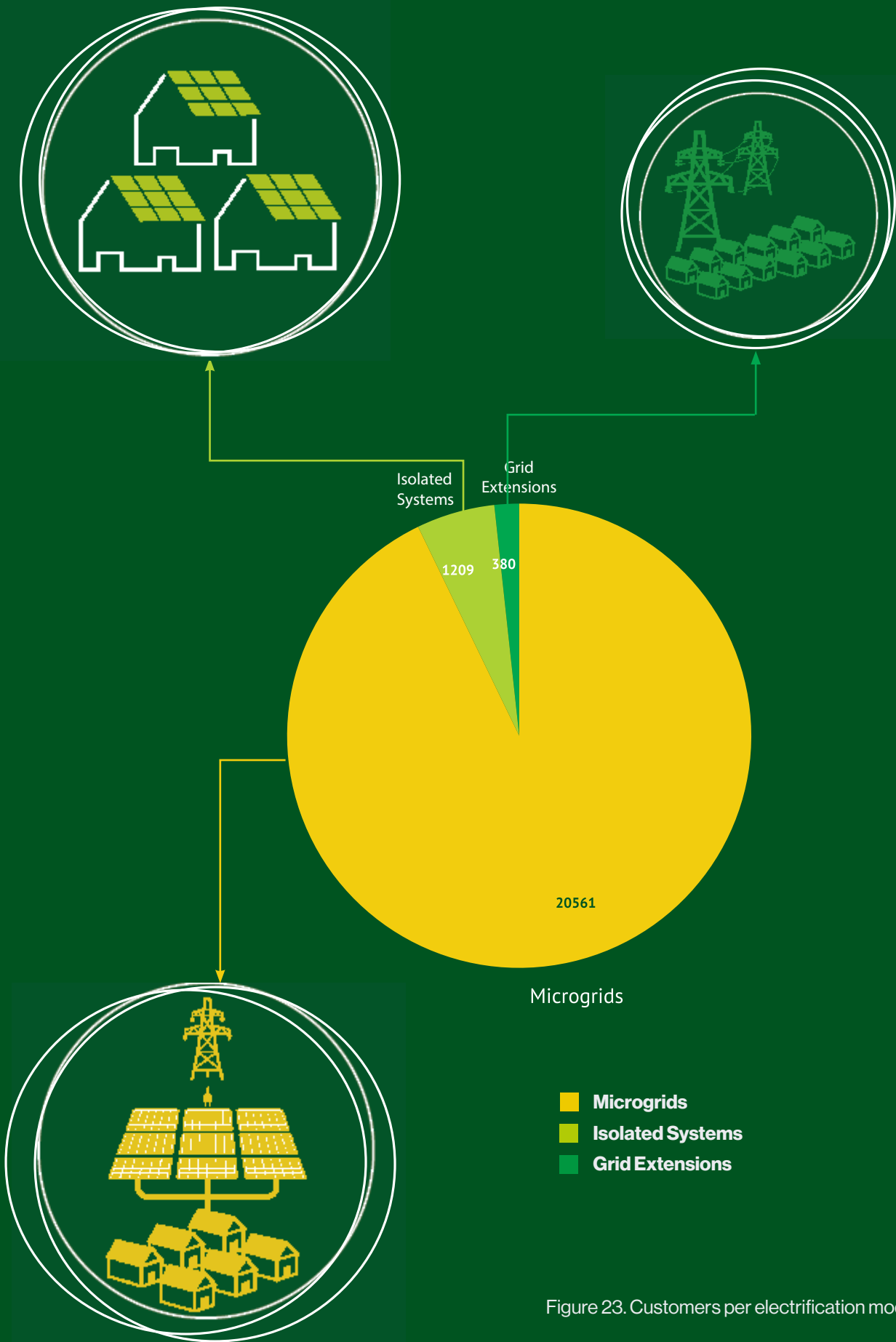


Figure 23. Customers per electrification mode.

Table 7 indicates the number of projects to be executed in the next years to achieve total electrification of the rural areas, and the average annual energy demand per user. Figure 24 shows the total investment cost, and the average investment cost per user.

	Mini grid	Isolated Sys-tems	Grid Exten-sions	All
Number of projects	142	48	5	195
Annual Energy Per Customer (kWh/yr)	1,078.98	1,715.76	1,090.20	
Investment Cost (USD)	92,178,096	8,469,943	1,214,143	101,862,182

Table 7 . Base case scenario results.

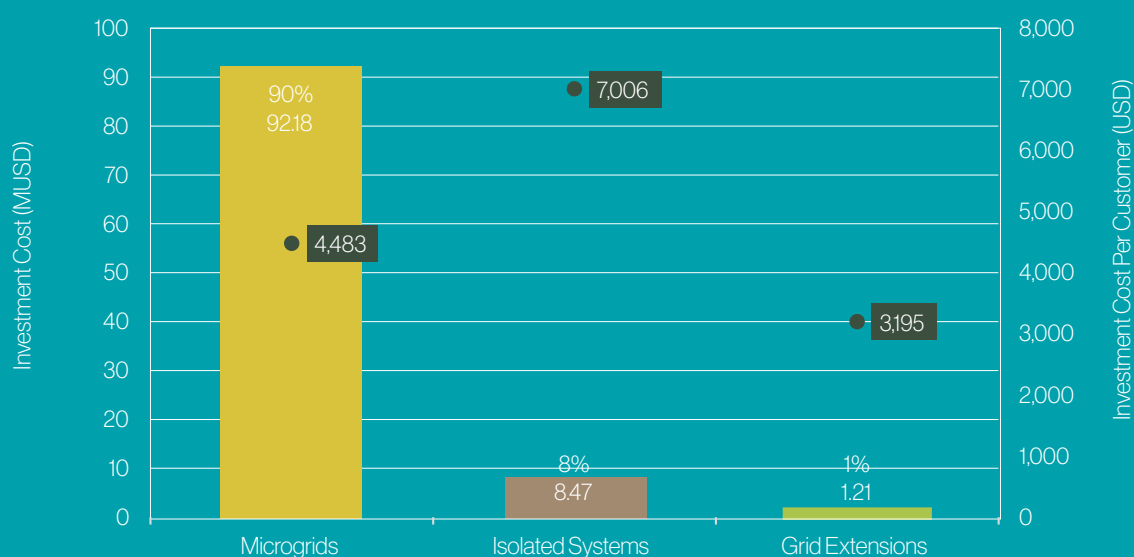


Figure 24. Investment per electrification mode.

The total investment cost per user is lower for electrification project in the Urban region, and the highest for projects in Southwest region (Table 8).

Region	Urban	Central South-east	Southwest
Average investment cost per user	4,185	5,650	5,804

Table 8 . Investment cost per user per region.

Table 9 and Figure 25 shows that LCOE is the lowest for grid extension projects, and the highest for isolated individual systems projects.

Region	Mini grid	Urban	Central southeast	Southwest
Demand Served (System Cost) (USD/kWh)	0.656	0.761	0.515	0.661
Demand Served (Total Supply Cost) (USD/kWh)	0.663	0.938	0.517	0.681

Table 9 . LCOE base case scenario results.

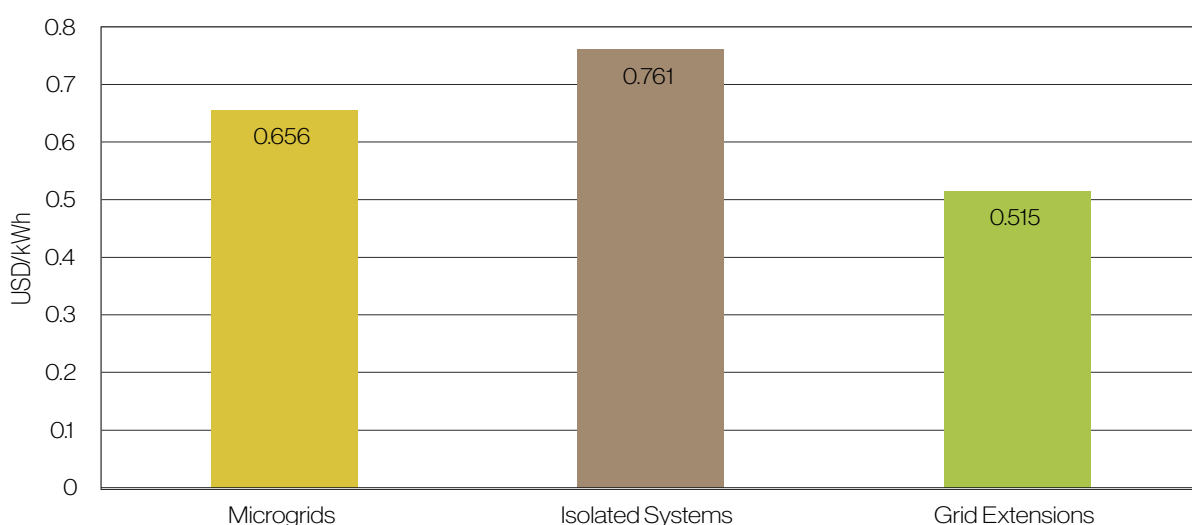


Figure 25. LCOE per electrification mode.

	Mini grids	Isolated Systems	Grid Extensions	All
Annuity CAPEX Per Customer (USD/yr)	615.33	920.45	407.38	628.42
Annuity OPEX Per Customer (USD/yr)	89.14	407.35	149.13	107.53
Annuity TOTEX Per Customer (USD/yr)	704.47	1,327.80	556.5	735.95
Total Annuity CAPEX (USD/yr)	12,651,795	1,112,827	154,803	13,919,425
Total Annuity OPEX (USD/yr)	1,832,715	492,486	56,668	2,381,868
Total Annuity TOTEX (USD/yr)	14,484,509	1,605,313	211,471	16,301,293

Table 10 . CAPEX and OPEX base case scenario results.

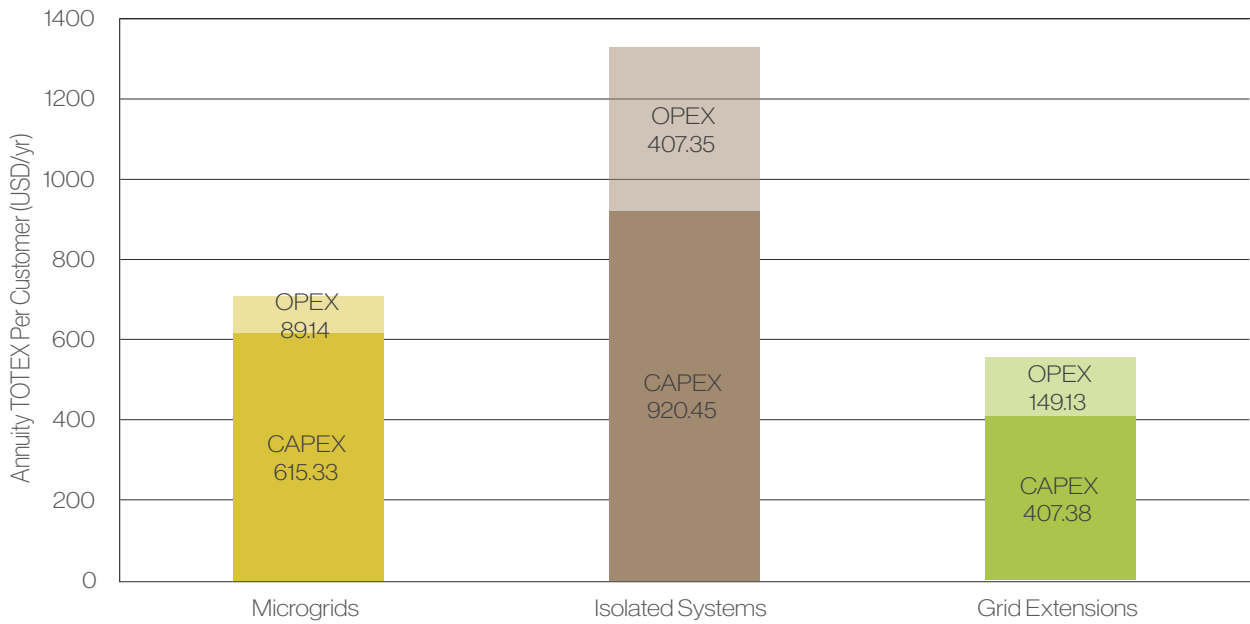


Figure 26. Service cost per electrification mode and customer.

Table 11 indicated the total energy consumption per electrification mode. The service reliability is considered high for mini grids and grid extension, while users electrified by isolated individual systems have a lower reliability on average.

	Mini grids	Isolated Systems	Grid Extensions	All
Annual Energy (MWh/yr)	22,185	2,074	414	24,674
Fraction of Demand Served (p.u.)	0.984	0.825	0.987	0.971
Total Non-served Energy Cost (USD/yr)	224,903	42,682	2,939	270,524
Annual Non-served Energy Cost Per Customer (USD/yr)	10.94	35.3	7.73	12.21

Table 11. Base case scenario demand served and non-served.

Diesel consumption is not recommended for mini grids in Central Southeast and Southwest regions, only in communities closer to the Urban region, therefore solar PV capacity and battery sizing are lower in this region.



4.1. On going projects

Table 12 . On-going projects.

ID	Settlement	Type of project	Promoter
1	Kwamalasamutu	Solar PV and battery mini grid	IADB
2	Sipaliwini		
3	Alalapadu		
4	Apetina + Akani + Halala + Tutu		
5	Palumeu		
6	Peleloe Tepoe		
7	Amatopo		
8	Coeroeni		
9	Kawamhakan		
10	Kumakapan		
11	Gingeston	Solar, diesel and battery mini grid	Under construction, EU and IADB
12	Pamboko (Budumatu)		
13	Amakakonde		
14	Abenaston (Sukunale)		
15	Kajapati		
16	Jawjaw		
17	Lesipaansi		
18	Adawai		
19	Gunzi		
20	Nieuw-Aurora (Nieuw-Aurora)		
21	Kwakoegron	Grid extension	Designed by EBS
22	Bigi Poika		
23	Bigiston	Grid extension	Under construction (PBM-Albina)
24	Wanhatti		
25	Langa Uku 1		
26	Langa Uku 2		
27	Tamarin		

	Mini grids	Isolated Systems	Grid Extensions	All
Number of Customers	16,240	468	383	17,091
Fraction of Customers	0.95	0.03	0.02	1
Number of projects	117	41	5	163
Investment Cost (USD)	73,760,402	3,278,687	1,235,161	78,274,251

Table 13 . Base case scenario results without on-going projects and presumed abandoned villages



4.2. Electrification modes highlights and examples

4.2.1. Mini grids

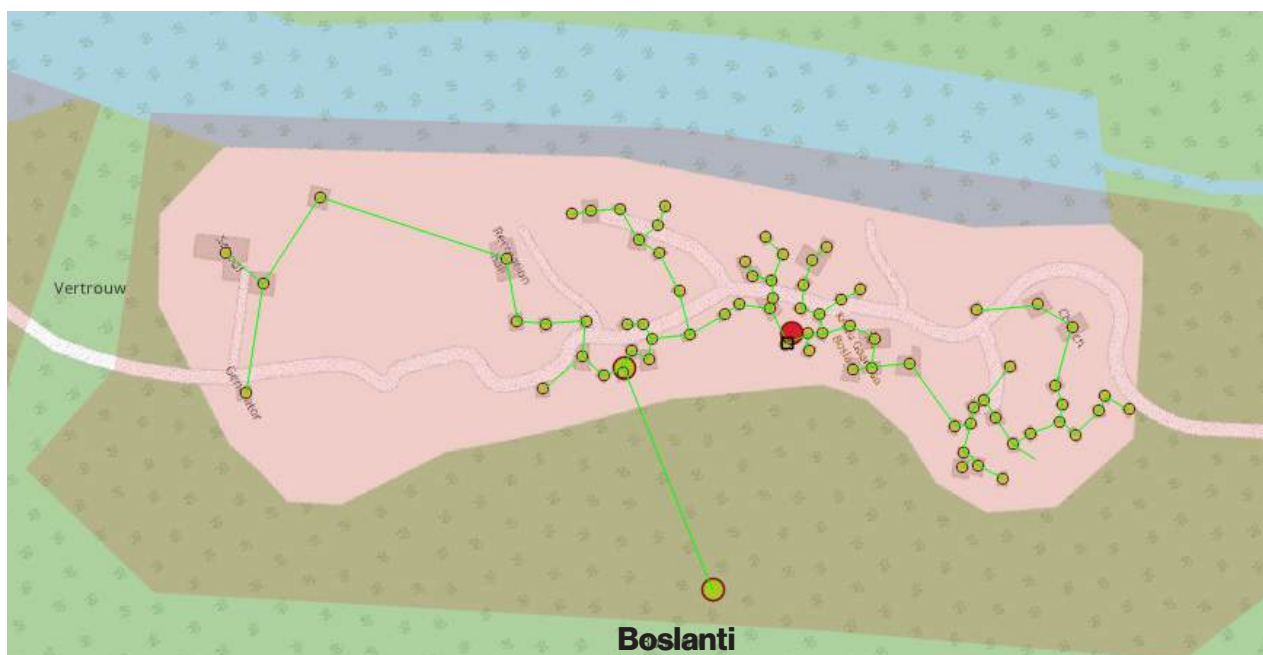


Figure 27. Mini grid example in Boslanti (Matawai).

Parameter	Value
Users	(3,968)
Capacity (solar + diesel)	85 kW + 5 kW
Peak demand (kW)	23.13 kW 7,392
Battery capacity (kWh)	243 kWh (729)
Overnight investment	USD \$350,089



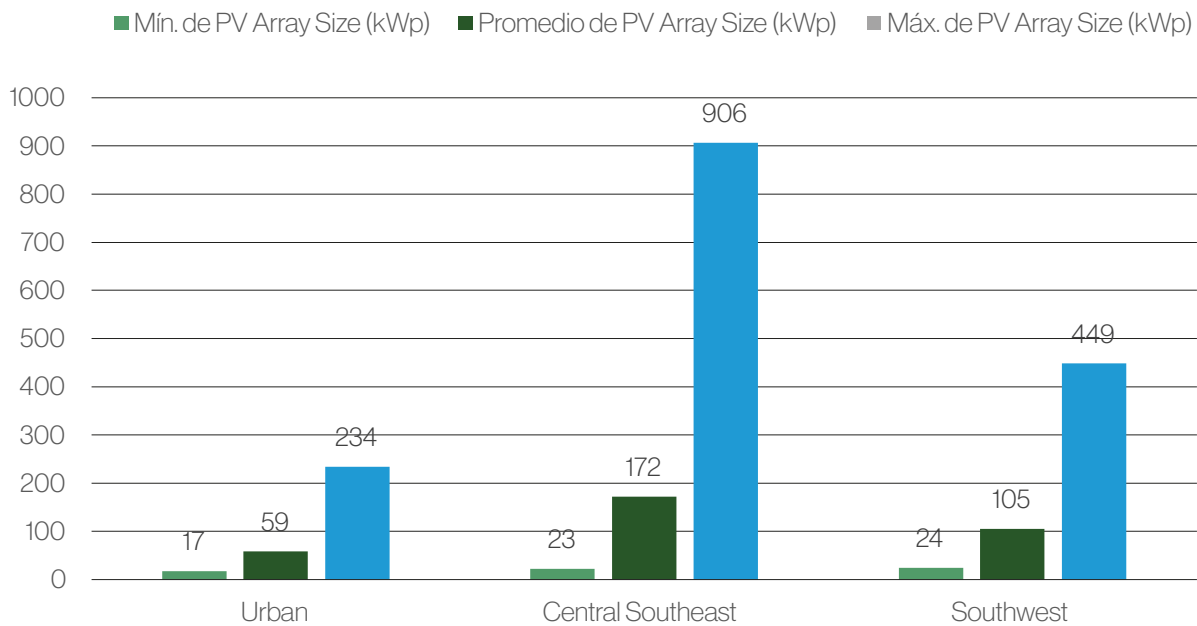


Figure 28. Solar PV average capacity of mini grids per region .

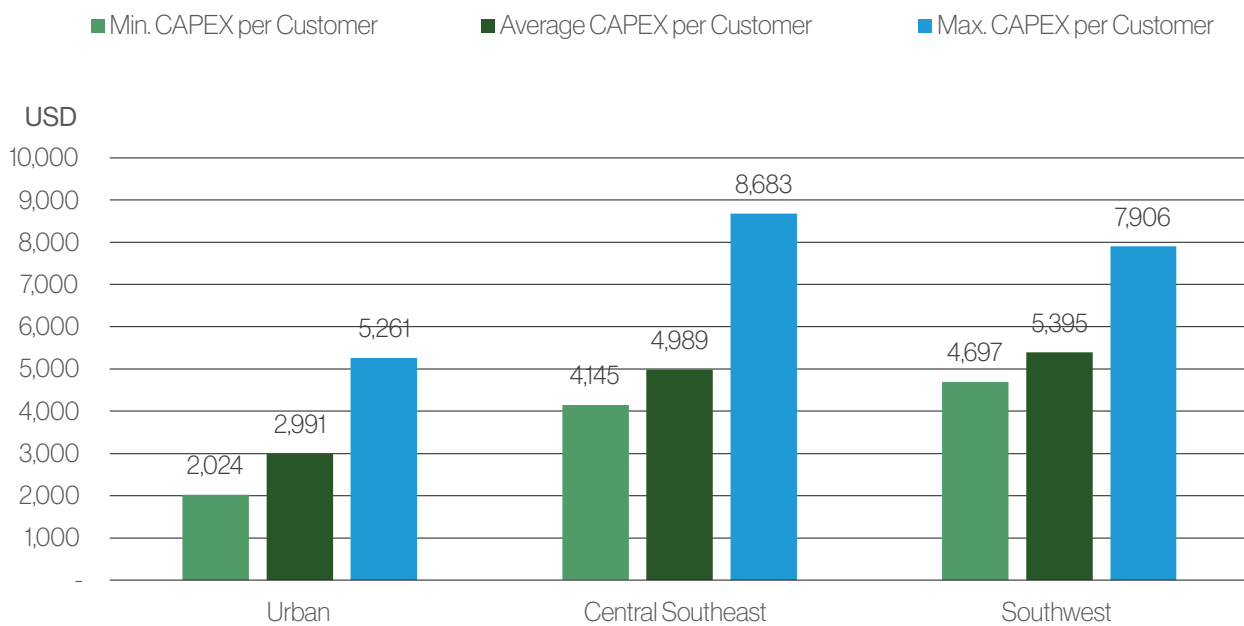


Figure 29. Mini grids investment cost per user per region .

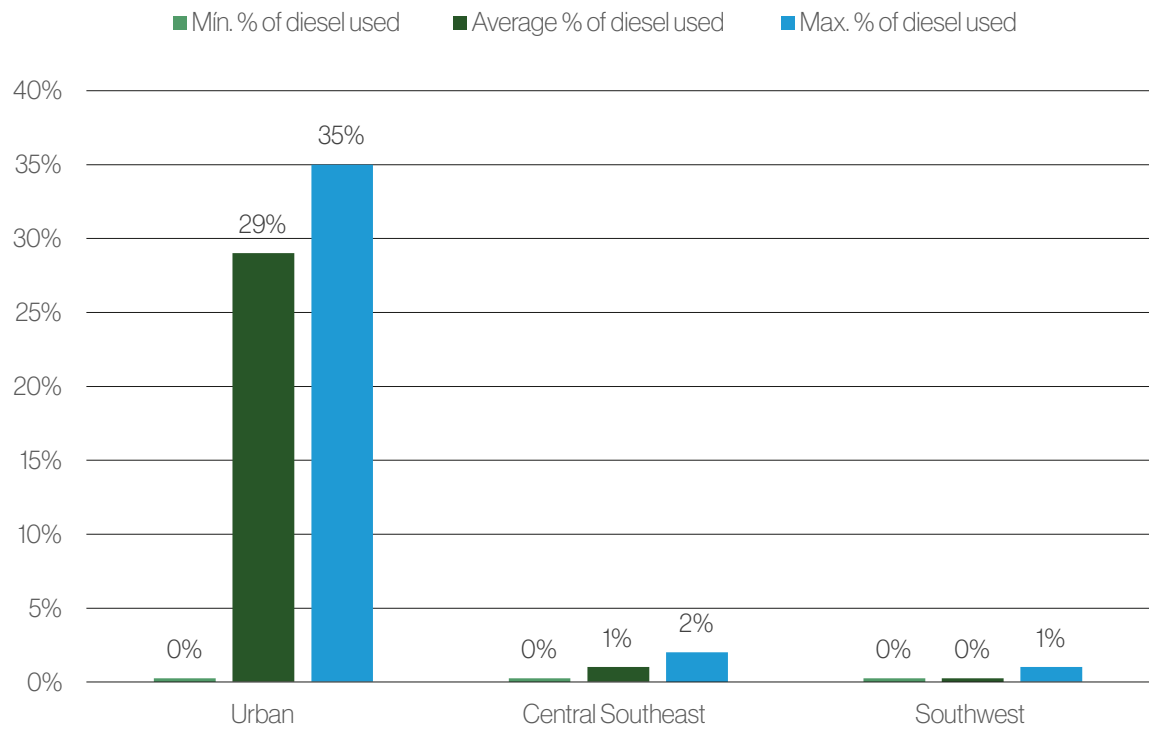


Figure 30. Diesel consumption for hybrid mini grids per region. .



4.2.2. Isolated individual systems

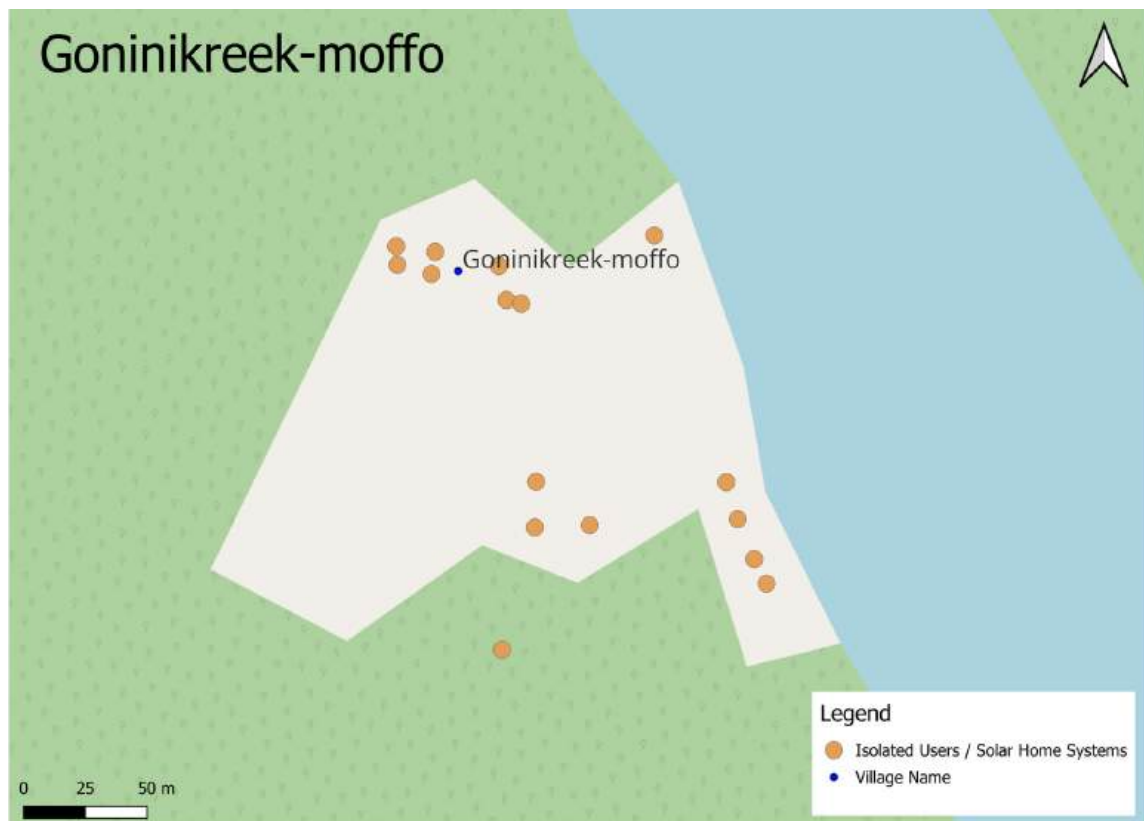


Figure 31. Isolated systems example in Goninikreek-moffo.

Parameter	Value
Users	16
Solar capacity	16.98 kW
Peak demand (kW)	4.8 kW
Battery capacity (kWh)	94.26 kWh
Overnight investment	USD \$112,091

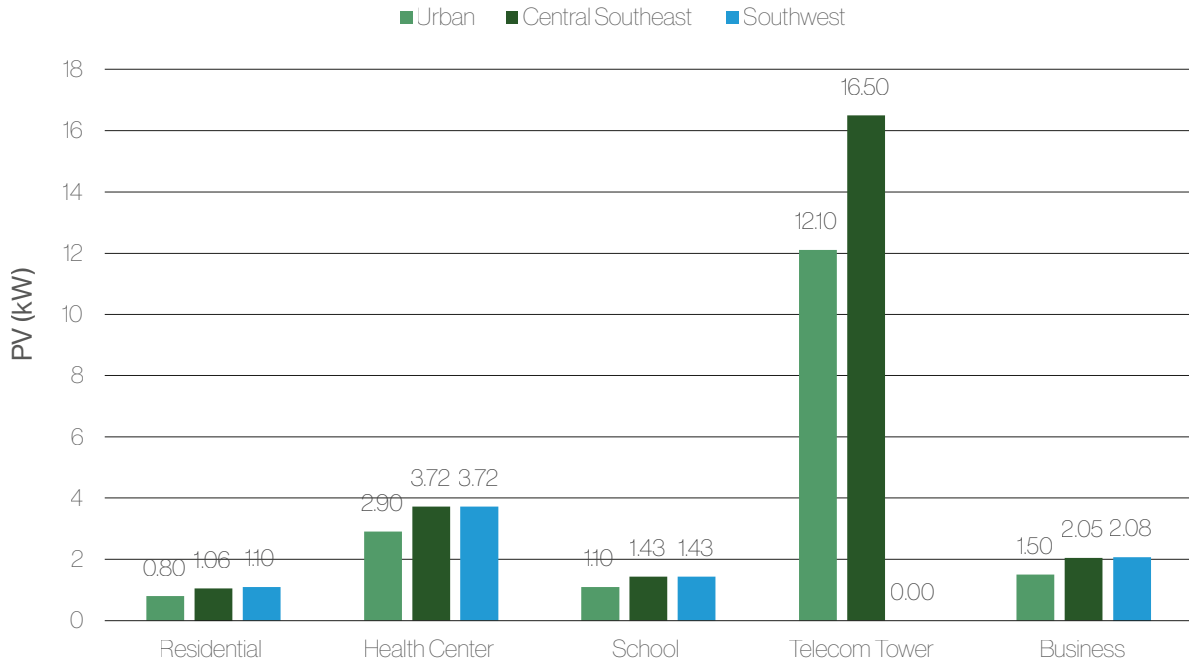


Figure 32. Solar PV average capacity of isolated individual systems per type of user and region .

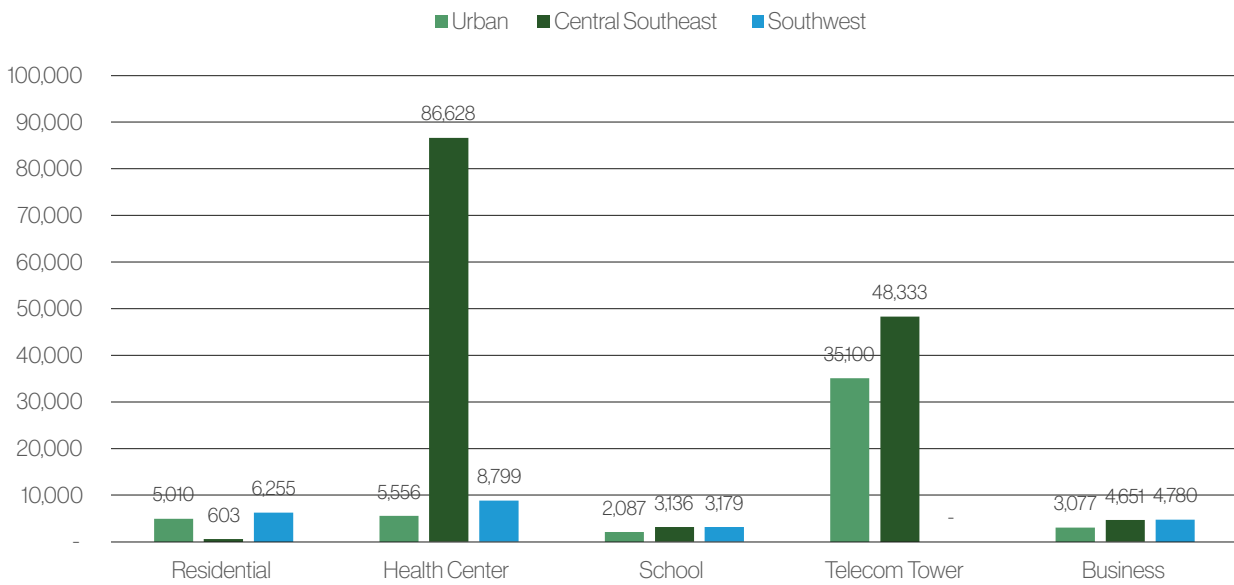
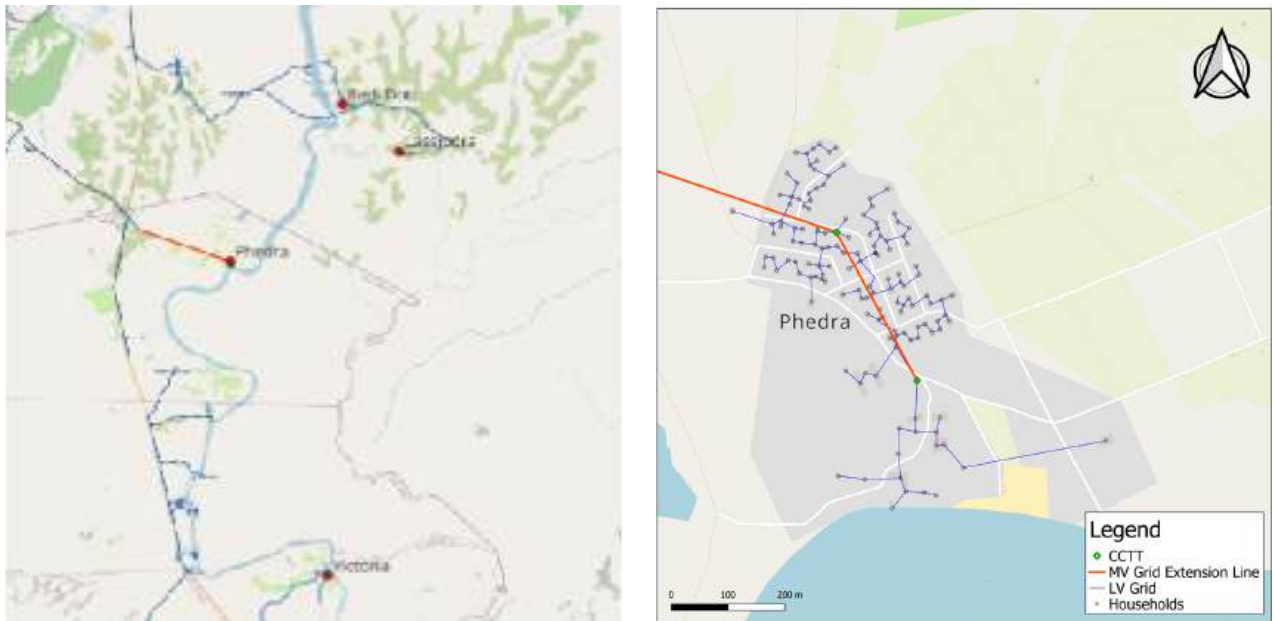


Figure 33. Isolated individual systems investment cost per type of user and region .

4.2.3. Grid extension



Parameter	Value
Users	151
Peak demand (kW)	145 kW
Grid extensión MV (km)	6.6
Grid extensión LV (km)	3.32
Overnight investment	USD \$460,765
Average line cost per km	46,000 USD/km

Figure 34. Grid extension example in Phedra.



5. Sensitivity scenarios results

The base case scenario proposes a first optimization model where the sizing and calculation of the least costly combination of grid extensions, mini-grids and stand-alone systems is optimized according to assumptions described in Table 14. However, if the choice of inputs and assumptions change, investment and sizing might change.

Through three additional sensitivity scenarios (S1, S2 and S3) the impact of different strategic options for the least-cost electrification plan is estimated.

	Base case scenario	S1 – Socio economic scenario	S2 – International benchmark scenario	S3 – Environmental scenario
Energy demand	Estimation based on surveys from rural areas in the north and south of the country. Average 2.9 kWh/day, 87 kWh/month, 1,026 kWh/year	Demand energy consumption variation per customer: ±15%	Estimation based on surveys from rural areas in the north and south of the country. Average 2.9 kWh/day, 87 kWh/month, 1,026 kWh/year	Estimation based on surveys from rural areas in the north and south of the country. Average 2.9 kWh/day, 87 kWh/month, 1,026 kWh/year
Population growth	1.1% Urban 0.83% Central Southeast 0.83% Southwest	1.1% Urban 0.83% Central Southeast 0.83% Southwest	1.1% Urban 0.83% Central Southeast 0.83% Southwest	1.1% Urban 0.83% Central Southeast 0.83% Southwest
Technical and cost data of distribution network	EBS (LV, MV lines, transformers, connection)	EBS (LV, MV lines, transformers, connection)	Lower grid components costs: -30%	EBS (LV, MV lines, transformers, connection)
Technical and cost data of off-grid	Manufacturers and services providers (panels, batteries, etc.)	Manufacturers and services providers (panels, batteries, etc.)	Manufacturers and services providers (panels, batteries, etc.)	Manufacturers and services providers (panels, batteries, etc.)
O&M	8 \$/user/year - Grid extension 12 \$/user/year - Isolated systems 10 \$/user/year - Mini grids	8 \$/user/year - Grid extension 12 \$/user/year - Isolated systems 10 \$/user/year - Mini grids	8 \$/user/year - Grid extension 12 \$/user/year - Isolated systems 10 \$/user/year - Mini grids	8 \$/user/year - Grid extension 12 \$/user/year - Isolated systems 10 \$/user/year - Mini grids

Table 14 . Base case scenario vs. sensitivity scenario.



	Base case scenario	S1 – Socio economic scenario	S2 – International benchmark scenario	S3 – Environmental scenario
SHS size	Estimated according to energy demand	Estimated according to energy demand	Estimated according to energy demand	Estimated according to energy demand
Diesel use	Allowed depending on cost* 1-4 USD/lt	Allowed depending on cost* 1-4 USD/lt	Allowed depending on cost* 1-4 USD/lt	100% renewable energy.
Minimal number of users per mini grids	20	20	20	20
Reliability	98.7%	98.7%	98.7%	98.7%



S1 – Socio economic scenario: in this scenario, the energy demand consumption of residential users is modified by $\pm 15\%$, considering a hypothetical case where the current regulation might change in the future or rural communities' energy demand is different from the one estimated in the base case scenario.



S2 – International benchmark scenario: in this scenario, the cost of grid extensions projects is reduced by 30%, considering a hypothetical case where materials and logistics costs are closer to international benchmarking for medium and low voltage lines.



S3 – Environmental scenario: in this scenario, only 100% renewable energy systems are allowed, and no hybrid energy systems are proposed, considering that no diesel will be transported to rural areas in the future, and looking further into the Energy Policy in Suriname based on three (3) pillars, namely: 1. Energy access for all; 2. To promote energy efficiency; and 3. To promote the use of renewable energy.



Figure 34 and Figure 35 contrast the results of the base case and sensitivity scenarios in terms of number of users per electrification mode and total investment to electrify all rural communities.

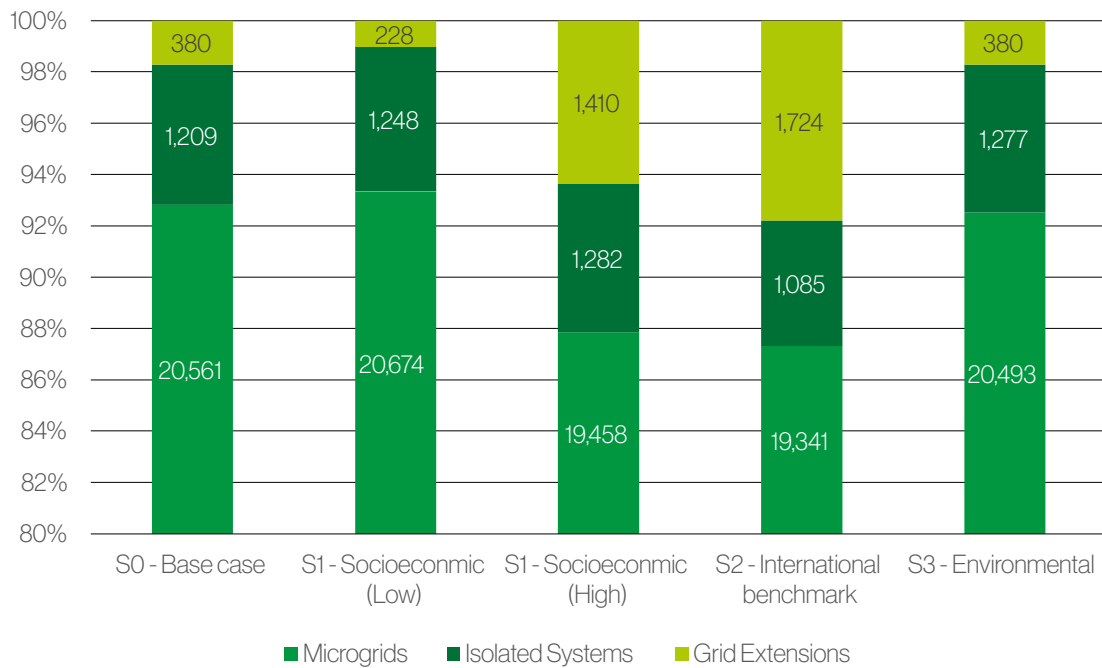


Figure 35. Number of customers per electrification mode for all scenarios.

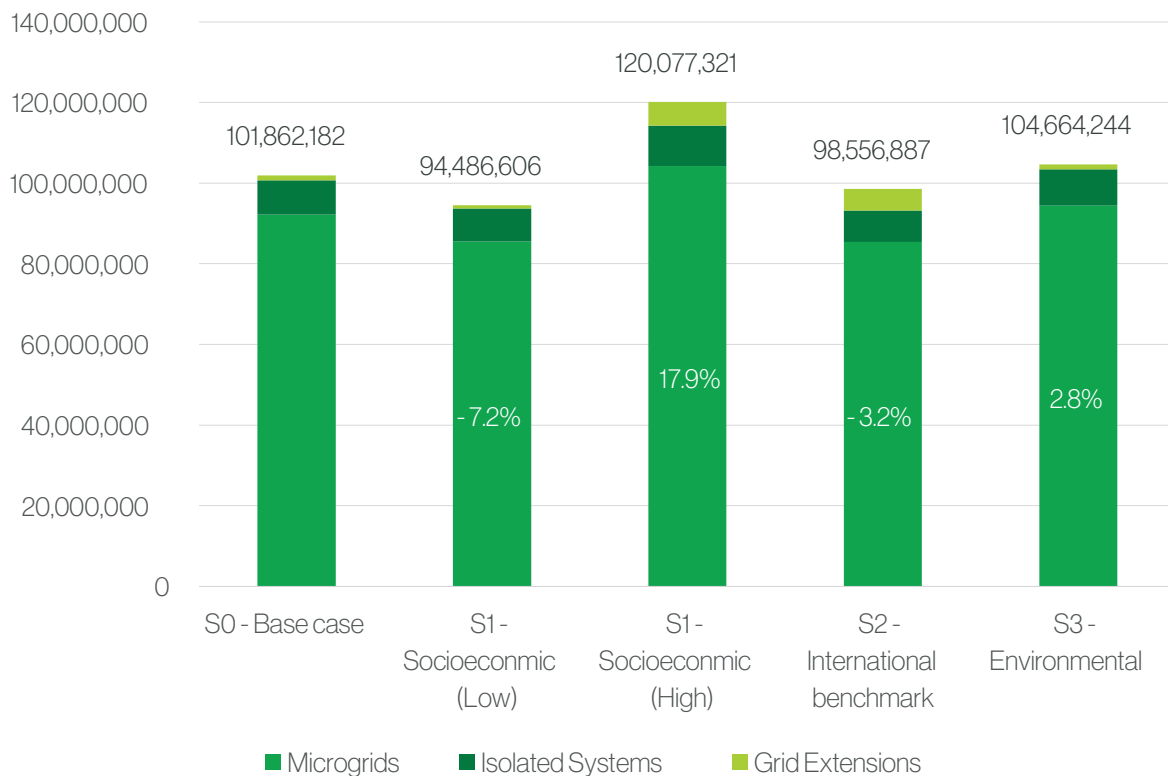


Figure 36. Total investment (USD) for all scenarios.

5.1. Scenario 1: Socio economic scenario

As a result of an energy demand increase for residential users, the sizing of mini grids and isolated individual systems is also increased and consequently the total investment for electrifying all rural areas increase by 17.9%. Similarly, as a result of an energy demand decrease for residential users, the sizing of mini grids and isolated individual systems is also decreased and consequently the total investment for electrifying all rural areas is reduced by 7.2%. It showcases that when reducing the demand for the consumers, the budget difference is less substantial than aiming to provide access to a much higher load, when the investment costs increase much more significantly.

S0					S1 – Demand decrease			
	Mini grids	Isolated Systems	Grid Ex-tensions	All	Mini grids	Isolated Systems	Grid Ex-tensions	All
Number of Customers	20,561	1209	380	22,150	20,674	1,248	228	22,150
Fraction of Customers	0.93	0.05	0.02	1	0.93	0.06	0.01	1
Investment Cost (USD)	92,178,096	8,469,943	1,214,143	101,862,182	85,512,699	8,227,138	746,769	94,486,606
Investment Cost Per Customer (USD)	4,483	7,006	3,195	4,599	4,136	6,592	3,275	4,266

Table 15 . Sensitivity scenario 1 results – Demand increase.

S0					S1 – Demand increase			
	Mini grids	Isolated Systems	Grid Ex-tensions	All	Mini grids	Isolated Systems	Grid Ex-tensions	All
Number of Customers	20,561	1209	380	22,150	19,458	1,282	1,410	22,150
Fraction of Customers	0.93	0.05	0.02	1	0.88	0.06	0.06	1
Investment Cost (USD)	92,178,096	8,469,943	1,214,143	101,862,182	104,263,440	10,042,376	5,771,505	94,486,606
Investment Cost Per Customer (USD)	4,483	7,006	3,195	4,599	5,358	7,833	4,093	5,421

Table 16 . Sensitivity scenario 1 results – Demand decrease.

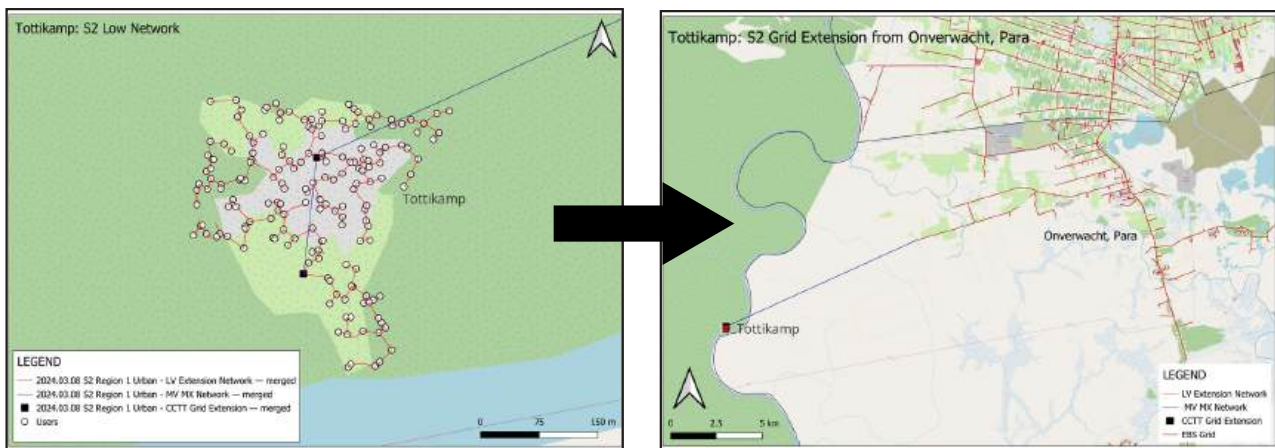
5.2.Scenario 2: International benchmark scenario

As a result of a cost decrease of the km of line for grid extension projects, some rural communities that were electrified by mini grids in the base case scenario, are now electrified by grid extensions projects, and the total investment is reduced by a 3.2%.

However, as shown in Table 18, less than 200 users are target of this change of electrification mode, showing that the base case scenario is fairly robust and that the geographical/topographical conditions of the country does not makes cost-effective to extend the grid in the rural areas, even if significant cost reductions are achieved in grid extension projects.

Parameter	Mini grids	Isolated Systems	Grid Extensions	All	Mini grids	Isolated Systems	Grid Ex-tensions	All
Number of Customers	20,561	1209	380	22,150	19,341	1085	1,724	22,150
Fraction of Customers	0.93	0.05	0.02	1	0.87	0.05	0.08	1
Investment Cost (USD)	92,178,096	8,469,943	1,214,143	101,862,182	85,454,649	7,744,079	5,358,159	98,556,887
Investment Cost Per Customer (USD)	4,483	7,006	3,195	4,599	4,418	7,137	3,108	4,450

Table 17. Sensitivity scenario 2 results.



Parameter	Value
Users	199
Peak Demand (kW)	58.8 kW
Capacity (Solar + Diesel)	100.5 kW + 18 kW
Battery Capacity (kWh)	255 kWh
Overnight Investment	USD 402,697

Parameter	Value
Users	199
Peak Demand (kW)	58 kW
Grid Extension MV (km)	11.61 km
Grid Extension LV (km)	2.42 km
Overnight Investment	USD 449,278

Figure 37. S2 electrification mode example in Tottikamp.

5.3. Scenario 3: Environmental scenario

If only mini grids of 100% renewable energy are allowed, some rural communities that were electrified by hybrid mini grids (diesel and PV solar energy, mostly in Urban region) in the base case scenario, are now electrified by mini grids with only solar PV energy, and less than 70 users would be electrified by isolated individual systems. The total investment is increased by a 2.7%. This is a low increase considering that all rural communities could be electrified by renewable energy only, and diesel would be suppressed completely.

Parameter	S0				S3			
	Mini grids	Isolated Systems	Grid Extensions	All	Mini grids	Isolated Systems	Grid Extensions	All
Number of Customers	20,561	1209	380	22,150	20,674	1,248	228	22,150
Fraction of Customers	0.93	0.05	0.02	1	0.93	0.06	0.01	1
Investment Cost (USD)	0.05	8,469,943	1,214,143	101,862,182	94,396,071	9,054,030	1,214,143	104,664,243
Investment Cost Per Customer (USD)	0.02	7,006	3,195	4,599	4,606	7,090	3,195	4,725

Table 18 . Sensitivity scenario 3 results.



6. Investment and financial strategy

6.1. Projects prioritization 2030 and 2035 horizon

Although the objective of the REP is to achieve 100% universalization of the electric energy service in the country, given the restrictions for the development of energy solutions, it is important to prioritize communities trying to maximize impacts on people's living conditions.

Considering the above, the MNH has approved the following indicative methodology for prioritizing communities, which considers technical, economic, and social variables.

It is important to note that despite the results of the prioritization analysis, the formulation and development of the projects are subject to the initiatives and proposals of the government and funders.

Table 20 shows the proposed calendar of implementation to electrify each community, considering that there are 27 communities with on-going electrification projects.

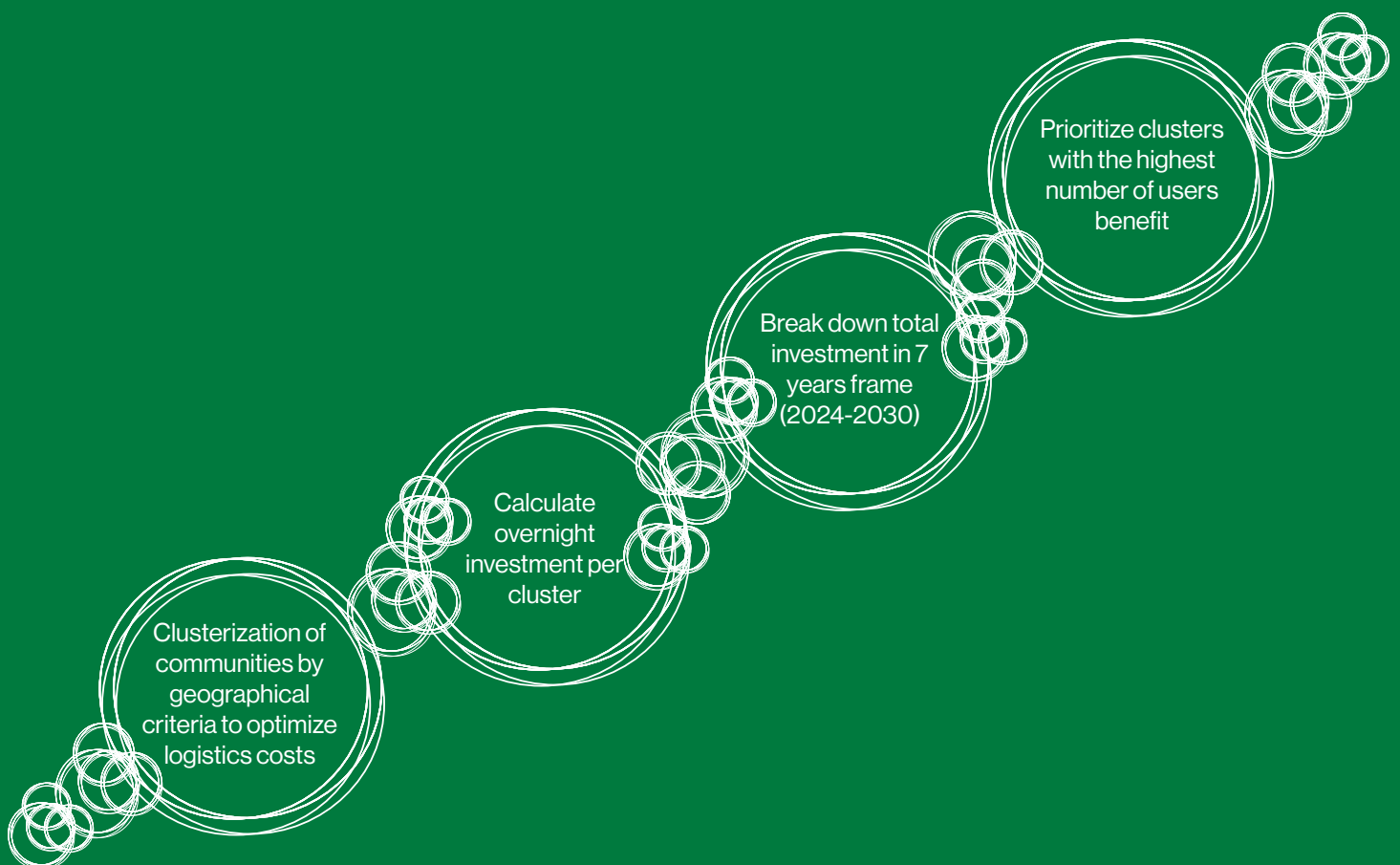


Figure 38. Investment and financial strategy

Cluster	Com-muni-ties	Number of users	Tribe	Year of execution 2030	Year of execution 2035	Total overnight investment	Accumulated overnight investment
3	11	2,863	Maroon	2024	2024	\$ 13,086,270	12.9%
1	14	5,218	Maroon	2025	2025-2026	\$ 22,996,187	35.4%
2	14	4,075	Maroon	2026	2027-2028	\$ 17,643,351	52.8%
4	21	933	Maroon	2027	2029-2030	\$ 5,084,980	57.8%
5	9	897	Maroon	2028	2030	\$ 4,990,057	62.7%
6	5	777	Indigenous		2031	\$ 4,098,107	66.7%
7	12	677	Maroon		2032	\$ 3,566,367	70.2%
8	4	557	Indigenous			\$ 3,125,567	73.3%
9	3	692	Maroon			\$ 2,773,440	76.0%
10	14	515	Maroon		2029	2033	\$ 2,722,610
11	10	473	Maroon	\$ 2,358,738			81.0%
12	5	753	Maroon Indigenous	\$ 1,985,448			82.9%
13	4	410	Indigenous	\$ 1,783,501		84.7%	
14	6	290	Maroon	2034		\$ 1,682,036	86.3%
15	8	272	Maroon			\$ 1,646,248	88.0%
16	2	411	Maroon		\$ 1,609,798	89.5%	
17	8	495	Maroon Indigenous		\$ 1,596,632	91.1%	
18	2	280	Indigenous		\$ 1,481,766	92.6%	
19	4	262	Maroon		2030	\$ 1,344,548	93.9%
20	9	218	Maroon Indigenous	\$ 1,223,959		95.1%	
21	4	198	Maroon	\$ 1,058,619		96.1%	
22	2	98	Indigenous	\$ 684,049		96.8%	
23	4	166	Maroon	2035		\$ 618,074	97.4%
24	2	158	Maroon Indigenous			\$ 580,050	98.0%
25	3	129	Maroon			\$ 562,145	98.5%
26	1	151	Maroon			\$ 460,765	99.0%
27	4	12	Indigenous			\$ 72,118	99.5%
28	1	10	Maroon			\$ 70,057	99.5%
29	1	2	Indigenous	\$ 14,011		99.6%	
30	1	1	Maroon	\$ 7,006	99.6%		
31	5	12	Maroon	\$ 450,564	100.0%		
TOTAL	195	22,150				\$101,806,134	100.0%

Tabel 19. Proposed calendar of implementation to electrify each community

In the Annexes the composition of the clusters as well as the CAPEX and OPEX per community are displayed.

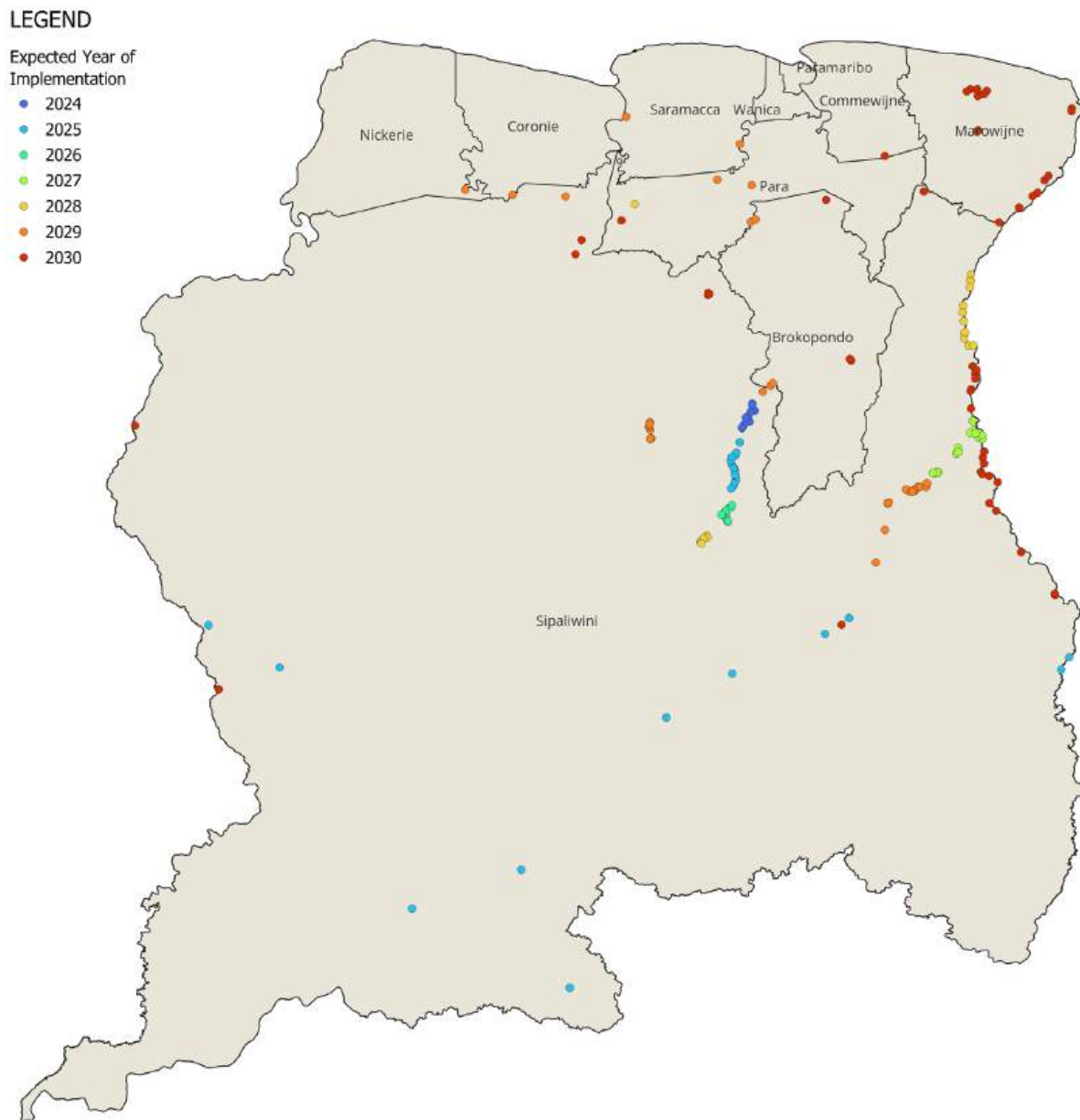


Figure 39. Proposed calendar of implementation to electrify each community, 2030 horizon.



Tutu Kampu, Apetina, TTA, 2023

7. Conclusions

- The total cost of electrification is US\$101.8 million, of which US\$1.2 million corresponds to grid extensions, US\$8.5 million corresponds to isolated systems and US\$92.1 million corresponds to mini grids.
- The expected demand in the reference scenario makes grid connection profitable for only 2% of the users, representing only 1% of the investment cost in the base case scenario (5 projects). Mini grids are the most efficient option for 93% of users, representing 90% of the investment cost (142 projects), and isolated systems represent 5% of users and account for 8% of the total investment cost (48 projects).
- Regarding the Levelized Cost of Energy (LCOE), grid extensions accounts for the lowest cost of energy with 0.515 USD/kWh, followed by mini grids with 0.656 USD/kWh, and isolated systems represent the highest cost with 0.761 USD/kWh since is the electrification mode which that takes less advantage of economies of scale.
- The Rural Electrification Plan considers the electrification of 195 communities (villages and camps) in Suriname, 27 of them are already being electrified or have investment resources approved for projects execution.
- Sensitivity scenarios allowed to measure the impact of possible alternative future scenarios in the planning:
 - **Scenario 1** - Socio economic scenario: if energy demand of residential users is reduced by 15%, the total investment will be reduced by 7.2% (\$ 94,486,606) and there will be 1% less users electrified by grid extensions. On the other hand, if energy demand of residential users is increased by 15%, the total investment will be increased by 17.9% (\$ 120,077,321) and there will be 4% more users electrified by grid extensions.
 - **Scenario 2** - International benchmark scenario: if cost of distribution lines (km) is reduced by 30%, the total investment will be reduced by 3.2% (\$ 98,556,887) and there will be 6% more users electrified by grid extensions.
 - **Scenario 3** - Environmental scenario: if only 100% renewable energy mini grids are allowed (no hybrid systems), the total investment will be increased by 2.8% (\$ 104,664,244), a small delta to ensure that no fossil fuels for electricity generation will be transported to rural communities.
- From the projections of available resources in 2024 and 2025 (15.7% of the total investment) for the electrification of new users, it is found that the rate of electrification is not sufficient to achieve the goal of universal service by 2030. Therefore, the continuity and sufficiency of the other financing mechanisms must be guaranteed, as well as adequate and timely regulations to continue developing projects to serve new users.
- Electricity supply initiatives to achieve the goal of universal service depends on funders, who structure the projects according to their needs and order of priorities. On going projects are limited mainly to state funds, however, private investment could accelerate rural areas electrification.
- Training and support in the structuring and presentation of projects, is of utmost importance for the fulfillment of the goals of the universalization of the electric power service.



Annexes

A. GIS Database

No.	Group	Database	Description	Source
1	Base layers	Districts	Administrative boundaries of the 10 districts of Suriname	SBB
2	Base layers	Hydrography	Prominent waterbodies in Suriname whereas rivers and lakes are projected	SBB
3	Base layers	Infrastructure Roads	Connection between two areas having a line structure, which can be paved or unpaved.	SBB
4	Base layers	Resorts	Administrative boundaries of the 63 resorts in Suriname	SBB
5	Base layers	Settlements and camps	Human settlements of any size. Settlements can be sub-categorized in Built area and Infrastructure.	SBB
6	Landuse & Land-cover	Basemap 2000	Shapefile projecting Suriname's forested, non-forested, shifting cultivation and hydrography areas	SBB
7	Landuse & Land-cover	LULC_2000_2021	Land Use and Land Cover from the year 2000 until 2021	SBB
8	Landuse & Land-cover	LULC_2020	Land Use and Land Cover from the year 2020	SBB
9	Protected Areas	Suriname Protected Areas	Shapefile projecting the protected areas in Suriname.	SBB
10	Topography	SRTM	Shape and elevation of surface features of Suriname	SBB

No.	Group	Database	Description	Source
11	Prohibited areas	Prohibited areas	2. Hydrography (lake polygon) and 9. Suriname Protected Areas layers overlap	TTA
12	DEV MNH 2023.06.24	DEV - Coordinates of Villages - TTA	DEV MNH villages with diesel generator	TTA
13	Admin boundaries	Admin boundaries	Suriname's Admin boundaries	SBB
14	Admin boundaries	Districts (Separated into 10 layers)	10 Separate layers of each district in Suriname	SBB/TTA
15	Rural - Central & Southeast Region	Rural - Central & Southeast Region	Layer of Central & Southeast Region Boundaries (includes only the following resorts: Tapanahony, Boven Saramacca, Boven Suriname, and Boven Coppename)	TTA
16	Rural - Central & Southeast Region	Health centers - Rural Central & Southeast Region	Layer containing Health centers within the boundaries of Central & Southeast Rural Region	TTA
17	Rural - Central & Southeast Region	Households - Rural Central & Southeast Region	Layer containing households within the boundaries of Central & Southeast Rural Region	TTA
18	Rural - Central & Southeast Region	Schools - Rural Central & Southeast Region	Layer containing public and private schools within the boundaries of Central & Southeast Rural Region	TTA
19	Rural - Central & Southeast Region	Telecommunication Towers - Rural Central & Southeast Region	Layer containing telecommunication towers within the boundaries of Central & Southeast Rural Region	TTA
20	Rural - Central & Southeast Region	Businesses - Rural Central & Southeast Region	Layer containing businesses within the boundaries of Central & Southeast Rural Region	TTA
21	Rural - Central & Southeast Region	Communities Polygons - Rural Central & Southeast Region	Layer containing all the community boundaries within Central & Southeast Rural Region	TTA
22	Rural - Central & Southeast Region	Households - Rural Central & Southeast Region	Layer containing households within the boundaries of Central & Southeast Rural Region (.CSV Format w/ Latlon Coordinates)	TTA

No.	Group	Database	Description	Source
23	Rural - Southwest Region	Rural - Southwest Region	Layer of Rural Southwest Region boundaries (includes only the following resorts: Kabalebo and Coeroeni)	TTA
24	Rural - Southwest Region	Health centers - Rural Southwest Region	Layer containing Health centers within the boundaries of Rural Southwest Region	TTA
25	Rural - Southwest Region	Households - Rural Southwest Region	Layer containing households within the boundaries of Rural Southwest Region	TTA
26	Rural - Southwest Region	Schools - Rural Southwest Region	Layer containing public and private schools within the boundaries of Rural Southwest Region	TTA
27	Rural - Southwest Region	Telecommunication Towers - Rural Southwest Region	Layer containing telecommunication towers within the boundaries of Rural Southwest Region	TTA
28	Rural - Southwest Region	Businesses - Rural Southwest Region	Layer containing businesses within the boundaries of Rural Southwest Region	TTA
29	Rural - Southwest Region	Communities Polygons - Rural Southwest Region	Layer containing all the community boundaries within the Rural Southwest Region	TTA
30	Rural - Southwest Region	Households - Rural Southwest Region	Layer containing households within the boundaries of Rural Southwest Region (.CSV Format w/ Latlon Coordinates)	TTA
31	Urban Region	Urban Region	Layer of Urban Region Boundaries (containing the following districts: Nickerie, Coronie, Wanica, Saramacca, Paramaribo, Commewijne, Marowijne, Para and Brokopondo)	TTA
32	Urban Region	Health centers - Urban Region	Layer containing Health centers within the boundaries of Urban Region Boundaries	TTA
33	Urban Region	Households - Urban Region	Layer containing households within the boundaries of Urban Region Boundaries	TTA
34	Urban Region	Schools - Urban Region	Layer containing public and private schools within the boundaries of Urban Region Boundaries	TTA
35	Urban Region	Telecommunication Towers - Urban Region	Layer containing telecommunication towers within the boundaries of Urban Region Boundaries	TTA

No.	Group	Database	Description	Source
36	Urban Region	Businesses - Urban Region	Layer containing businesses within the boundaries of Urban Region Boundaries	TTA
37	Urban Region	Communities Polygons - Urban Region	Layer containing all the community boundaries within the Urban Region Boundaries	TTA
38	Urban Region	Households - Urban Region	Layer containing households within the boundaries of Urban Region Boundaries (.CSV Format w/ Latlon Coordinates)	TTA
39	EBS Distribution	EBS gridlines 12kV	Layer containing all gridlines equal and below 12kV (by merging)	EBS/TTA
40	Future Energy Projects	Communities with Future Energy Projects	Layer containing all communities that are either confirmed or not confirmed to have energy projects in the (near) future	TTA
41	Building footprints	Non-electrified Building Footprints	Layer containing the Non-electrified buildings, houses or any infrastructure with roofs compiled from OSM, Google, and Microsoft.	TTA
42	Identified Communities	Communities Identified in Suriname	Layer with communities (electrified as Non-electrified) compiled from SBB, DEV and DC's.	SBB, DEV, DC's
43	Identified Non-electrified Communities	Non-electrified Communities - No Access	Layer containing only communities with no access to energy at all	TTA
44	Identified Non-electrified Communities	Non-electrified Communities - Dieselgen	Layer containing only with limited access to energy (diesel gen) but considered Non-electrified	TTA
45	Identified Electrified Communities	Electrified Communities - Connected to EBS grid	Layer containing community's centroid only that are connected to the EBS Distribution Grid	TTA
46	Health centers	Rural Health centers - unfiltered	Rural Health centers (Medical Mission/ Medische Zending)	MZ

No.	Group	Database	Description	Source
47	Private and Public Schools	Private and Public Schools in Suriname - unfiltered	Public and Private Schools compiled and unfiltered	OWC
48	Telecommunication Towers	Telecommunication Towers - unfiltered	Telecommunication Towers compiled and unfiltered (Digicel and Telesur)	Telesur, Digicel



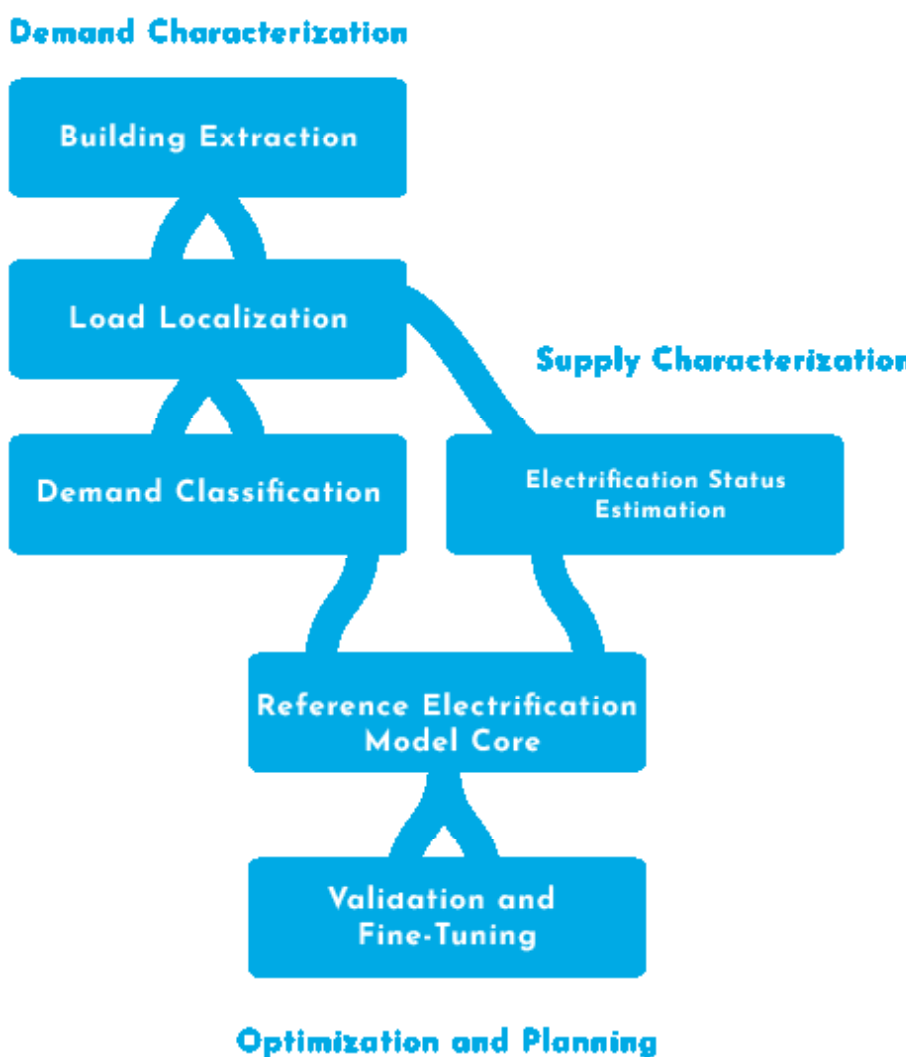
B. Reference Electrification Model (REM)

The REM⁶ developed jointly by the Massachusetts Institute of Technology (MIT) and Universidad Pontifical Comillas Institute for Research in Technology (IIT) supports the electrification planner when deciding which technology to use to supply electricity in any given territory (cell, village, or group of individual customers). REM makes use of geospatial computer-based techno-economic optimization algorithms to produce plans for distribution network expansion and off-grid systems for universal energy access. It allows decision-makers and planners to apply some policy objectives and to test assumptions easily by using computing power, leaving to the human planner, the final decision-making.

The outputs provided by REM rely on a combination of ground data, a carefully selected set of assumptions, and strategic decision-making, and as such, the tool should be used in close interaction with the lead agency and planning department.

For our master electrification planning projects, we have developed a pipeline of highly scalable machine learning techniques to comprehensively characterize both demand and supply characteristics over large areas to produce inputs for REM. As shown in Figure 39, this pipeline includes building extraction from satellite imagery, load localization, demand classification, and electrification status estimation.

Figure 40. Input data and inference pipeline designed for electrification planning in REM. (Source: Waya)



Objectives and methodology: Techno-economic procedure for least-cost electrification planning

⁶P. Ciller et al., "Optimal Electrification Planning Incorporating On- and Off-Grid Technologies: The Reference Electrification Model (REM)," Proceedings of the IEEE, Special issue, 2019.

REM is designed as a toolbox with several functions, which can be used to support a variety of use cases. The functions can be grouped into three categories: 1) fundamental algorithms, 2) structuring functions, and 3) auxiliary scripts/functions. The first category corresponds to those, which solve a particular problem independently from the use case, while the second includes code that performs simple operations such as comparisons or interpolations, which tend to be related to particular use cases. The third category deals with file input/output. The fundamental algorithms that have been developed till now include the following four key functions:

- **Clustering:** Groups buildings in relevant units of comparison;
- **Off-grid supply design:** Chooses the best off-grid supply components to meet an off-grid load;
- **Mini-grid network design:** Designs a distribution network for a mini-grid using the Reference Network Model; and
- **Grid extension design:** Designs a distribution network to connect a group of buildings to the existing distribution network.

REM performs two major steps: (1) individual demand clustering using a bottom-up approach and (2) a final decision on the best electrification mode for each cluster.

Before step 1, to avoid multiple detailed evaluations of the optimal generation mix for each one of the many cluster combinations, REM calculates optimal generation designs for representative off-grid systems and stores the corresponding data in a look-up table.

To find these generation designs, REM minimizes costs (both investment and operation costs plus a penalty for the amount of demand that is not met) using an optimization strategy with a master/slave strategy. The master optimization makes decisions about the design variables, using a direct pattern search approach, and the slave optimization performs a simulation with a load-following dispatch strategy for each representative mini-grid.

If in the clustering or the final designs' algorithm REM needs information related to a generation design that is not included in the look-up table, it interpolates using the closest designs. The generation technologies that REM presently considers for off-grid systems are solar, batteries, and diesel generation. The cost of the charge controllers and inverters is also included (if needed).

Step 1: Clustering

REM groups many buildings into potential electrical sub-systems. This step is very important because it will condition the spatial distribution of off-grid and on-grid systems. Since the actual number of clustering possibilities is unmanageable, REM implements the following strategy:

- A systematic bottom-up greedy algorithm, based on local decisions, builds clusters at two hierarchical layers, as shown in Figure 40. The first layer is built assuming only off-grid solutions, and then a second layer adds the possibility of grid extension.
- Local clustering decisions depend on the balance between savings (size-related economies of scale) and extra costs (network investments to connect buildings).
- Economies of scale result from size-related administrative or maintenance costs, network components/designs, and generation components/designs. The results depend critically on accurate inputs or estimations of these size-related factors.
- Since the number of possible local decisions may be huge in real-life problems, some simplifications have been made:
 - Connectivity options are limited to the subset of the most promising grouping solutions identified through graph theoretical methods.
 - Extra network costs are estimated by simplified representations of the networks.
 - Generation costs are obtained by interpolating in the look-up table calculated in the generation sizing block of REM.

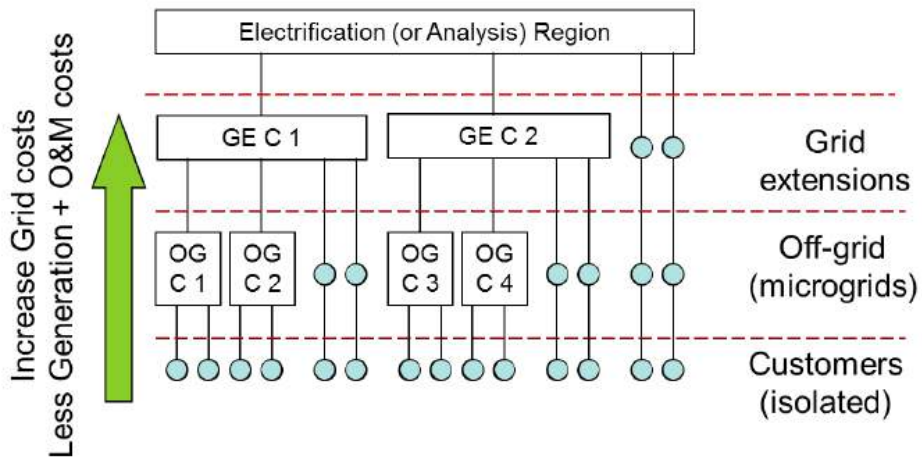


Figure 41. Example of the structure of clusters (results from the clustering process) (Source: Waya)

The goal of the clustering process is to determine which consumers should be electrified together (i.e., with the same system) and what is the most efficient way to electrify them. Evaluating all the possible combinations would be computationally unfeasible in large-scale problems. REM uses a Delaunay triangulation to obtain potential connections among consumers. This procedure has been used in clustering algorithms related to distribution networks in prior studies as well.

Figure 41 adds the candidate connections in an example set. Consumers 1 and 2 could be electrified together, but a direct connection between them and consumers 31 and 32 is not worth considering. However, when considering aspects such as economies of scale, there may be justification for the gradual aggregation of more customers until all of them happen to be connected in one large cluster.

The first step of the clustering process (off-grid clustering) temporarily assumes that all the consumers will be electrified individually with off-grid systems. The algorithm makes customer grouping decisions based on two conflicting driving factors: (1) the savings in generation, operation, and management costs brought by economies of scale and customer simultaneity factors in larger mini-grids, versus (2) the increment of network costs associated with grouping customers. REM begins by evaluating the arcs of the Delaunay triangulation that are more likely to be activated by joining the corresponding clusters, i.e., from the shortest to the longest link (the effect of the order of evaluation is mitigated by running several passes). In each evaluation, the model compares the costs of the configurations shown in Figure 42 to determine if the connection should be activated.

In the figure, triangles represent generation sites.

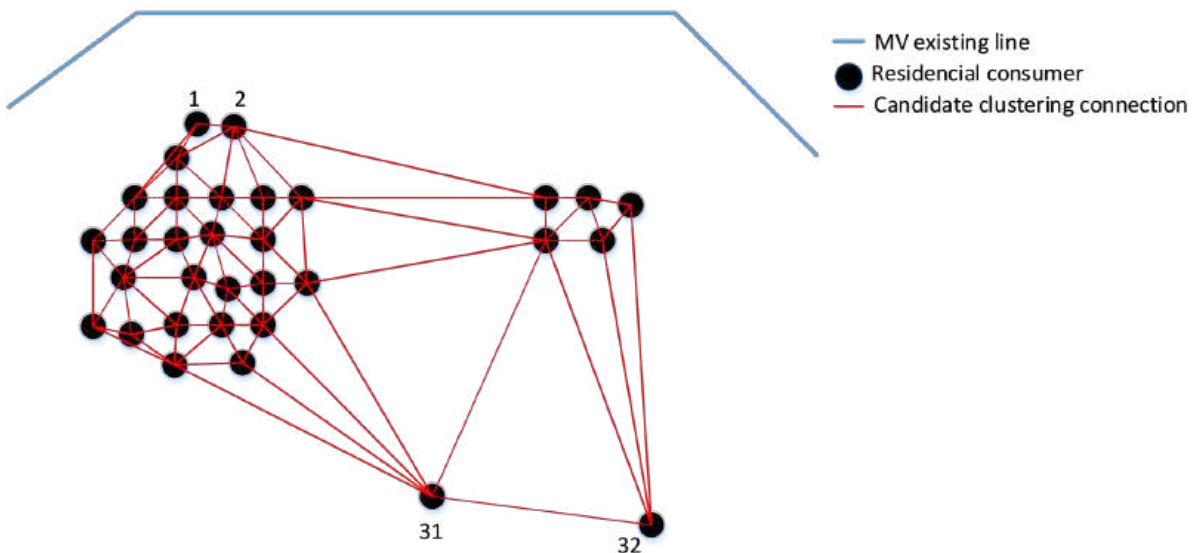


Figure 42. Clustering candidate connections



Figure 43. Off-grid clustering configurations

Configuration 1, where the clusters are separately electrified, has larger generation and management costs. On the other hand, the network cost of configuration 2 is larger (the line approximates the incremental network costs). REM estimates the cost difference between both configurations and joins the clusters if configuration 2 is less expensive.

Figure 43 shows a possible off-grid clustering solution with seven off-grid clusters for the example under consideration, and the Delaunay arcs that have not been activated.

Delaunay arcs are used as potential clustering connections; therefore, some of them may be redundant (if they link the same pair of clusters) and just ignored. The clusters at the end of this step are the off-grid clusters, and they are the starting point of the grid-extension clustering process.

The second step of the clustering process (grid-extension clustering) starts from the existing network and the off-grid clusters obtained in the first clustering step. Note that REM does not decide the final electrification modes in the clustering process. This is determined in the final design phase when the different alternatives derived from the clustering process are examined and final detailed comparisons are made. The grid-extension clustering makes use of the arcs of the Delaunay triangulation that join pairs of two different off-grid clusters. It

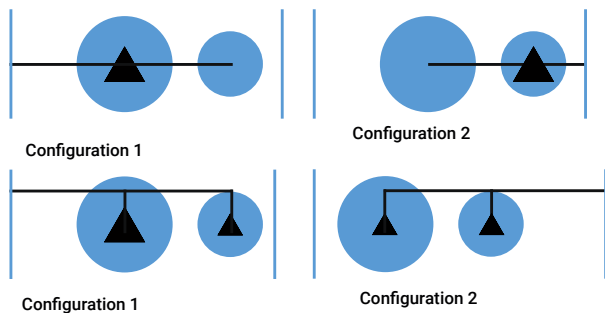


Figure 45. Set of alternative configurations that support merging grid extension clusters.

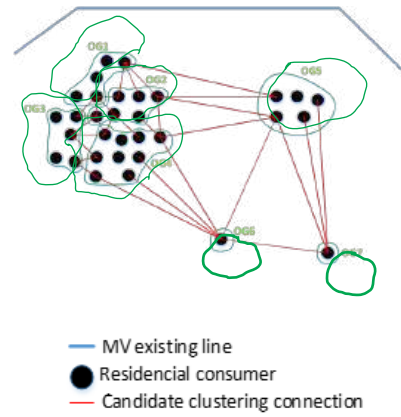


Figure 44. Off-grid clustering example

calculates the cost of several configurations to determine if it is worth joining both clusters, under the assumption that at least one of them is going to be connected to the grid. In the first set of configurations, which is shown in Figure 44, both clusters are connected with a line (triangles represent MV/LV transformers; thick lines are MV lines, and thin ones are LV lines). This implies that REM will join both clusters if a configuration from this set ends up being the least-cost one.

On the other hand, Figure 45 shows several configurations with the clusters not connected to one another. In configurations 3 and 4 one of the clusters is indeed electrified with an off-grid system (here triangles may be either transformers or generation sites). Hence, if a configuration from Figure 46 is the least-cost one then REM will not connect both clusters.

Following the example, Figure 46 shows the corresponding grid-extension clusters at the end of the grid-extension clustering process and the Delaunay arcs that have not been activated. In Figure 47, none of the clusters appears as connected to the MV grid, as the purpose of this grid-extension phase is not to decide on a grid connection but to get a better set of clusters that will be thoroughly analyzed in the final designs phase.

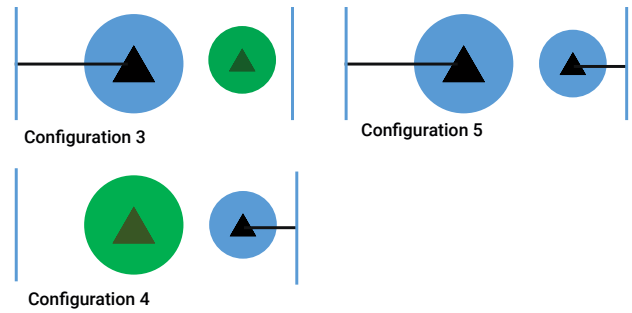


Figure 46. Set of alternative configurations that support keeping grid extension clusters separate.

The clustering process creates a hierarchical structure of clusters where the first level contains the grid-extension clusters, the second level contains the off-grid clusters, and the third level contains the individual consumers. Figure 47 shows the structure that corresponds to the example.

This cluster structure is used to determine the electrification mode of each consumer and the final solution. However, it is important to note that the origin of each cluster – either GE or OG – is completely ignored in the final design phase, and both electrification options

(off-grid and grid extension) are tried and evaluated in detail for all the clusters. The only goal of the clustering processes is to deliver a well-defined, compact, and meaningful structure of clusters to be thoroughly explored in the final design phase. Figure 48 shows a possible final electrification solution for the example under consideration. In this case, the cluster GE1 is electrified with a grid extension design whereas the remaining grid-extension clusters have lower costs when electrified with off-grid systems that are coherent with the hierarchical structure.

More in-depth details about the clustering process have been published in the peer-reviewed scientific journal⁷.

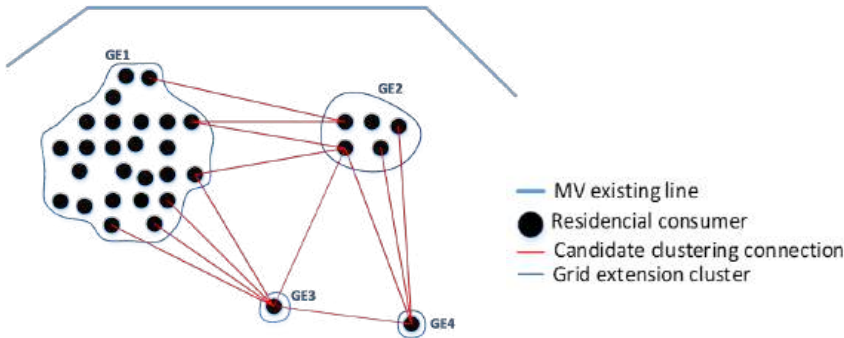


Figure 47. Grid-extension clustering example

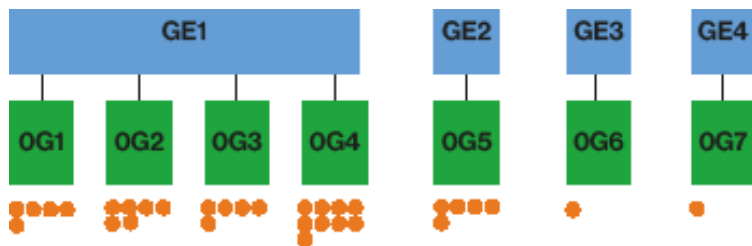


Figure 48. Hierarchical structure of clusters in the example

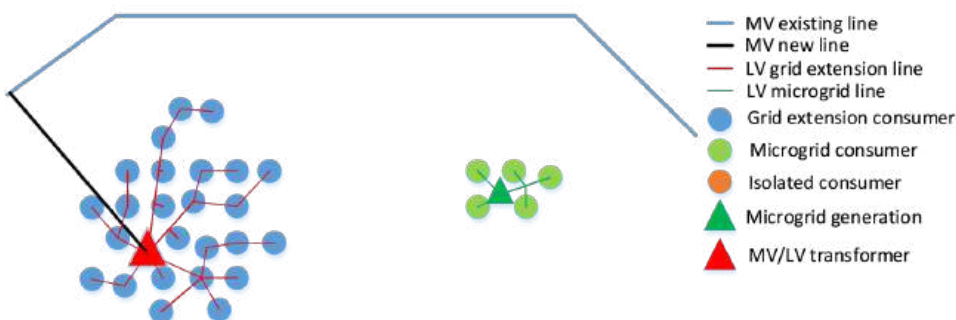
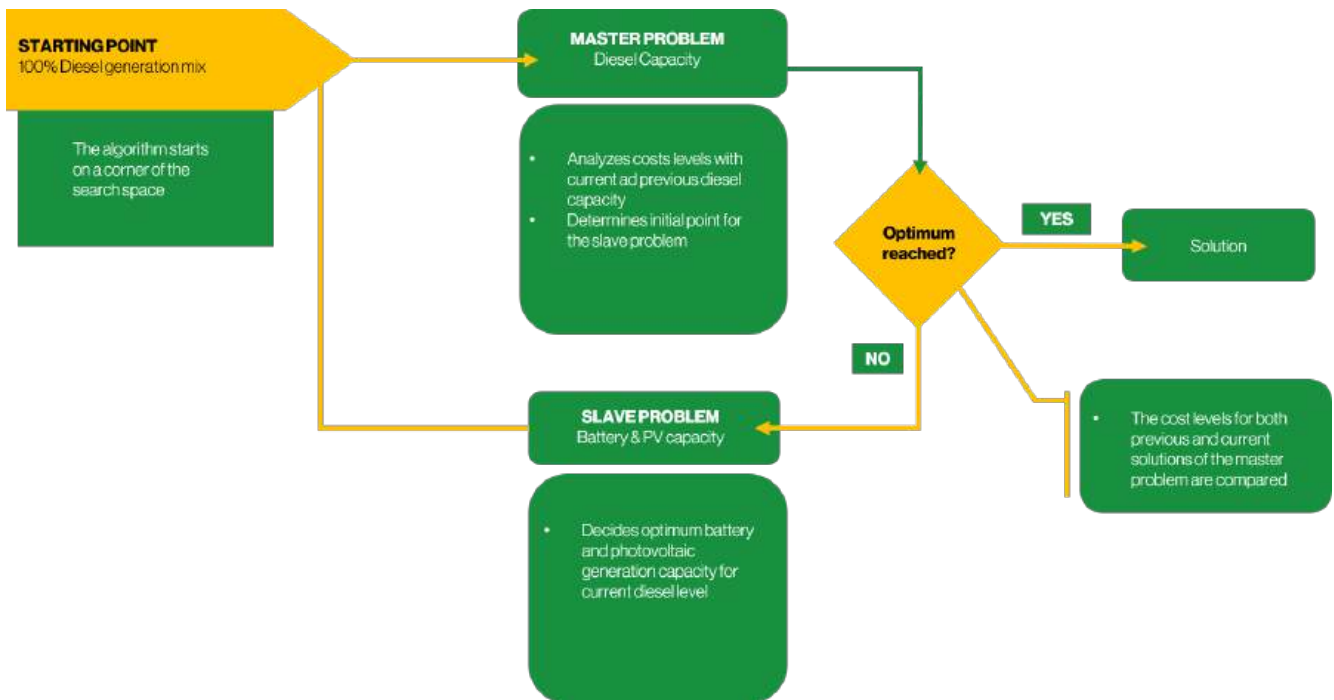


Figure 49. Final electrification solution



Step 2: Final decision on the best electrification mode for each cluster

After the clusters have been identified, the costs of the electrification options at different layers are calculated for each cluster as follows:

- **For the grid extension option:**

- Find the nearest viable connection points to the existing grid.
- Design the lowest-cost distribution network to connect the buildings to the grid. This is done using the Reference Network Model.
- Calculate the final cost, considering:
 - Cost of energy purchased from the grid.
 - Network costs (investment, maintenance, and losses).
 - Cost of non-served energy because of imperfect grid reliability.
 - Administrative and connection costs.

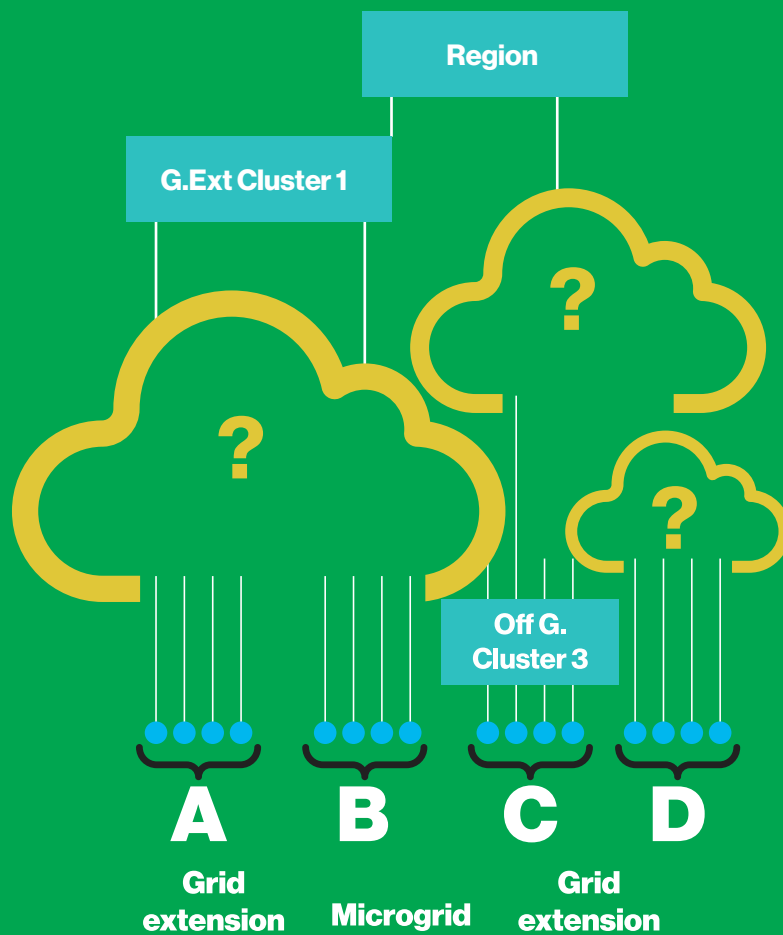
- **For the mini-grid option:**

- Calculate the cost of generation. This cost is either obtained by interpolating in the look-up table calculated in the generation sizing block of REM or by performing a full optimization process for this particular cluster, considering the hourly dispatch for the total consumption of the customers within a specific mini-grid.
- Calculate the network cost (RNM tool8, but adapted to a mini-grid case).

- Calculate the final cost, considering:
 - Generation costs (investment, operation, maintenance, and non-served energy).
 - Network costs (investment, maintenance, and losses).
 - Administrative and connection costs.

Different types of input data

As said before, the outputs provided by REM rely on a combination of ground data, a carefully selected set of assumptions, and strategic decision-making. The classification of inputs into these three groups is not always clear, so the following is just a reasonable example.



- Ground data. Inputs that are considered fixed data (although they may represent future plans or states of the system):
- Location of buildings. It is necessary to know the latitude and longitude of all buildings in the study area, as well as the type of building if different types of demand profiles are used.
- Existing distribution feeders (MV), and therefore the distances from buildings to the existing grid. The location of the existing distribution feeders and transformers must be obtained for the study area. In the absence of this data, it is possible to estimate it with the RNM tool (green field mode), provided that the already electrified customers are given.
- Energy resources (solar power availability, diesel cost if available and allowed, micro-hydro sites). The availability of different energy resources in a given area is necessary to determine the suitability of different types of generation.
- Topography data (altitude map and penalized areas). RNM and REM use these data to design networks and incorporate restrictions in the clustering step.
- Calculated assumptions. Inputs that are adjustable to different scenarios.
- Grid energy cost. Cost of energy estimated at MV feeders.
- Grid reliability. Reliability of the supply of electricity from the existing grid. The reliability metric can be expressed either as a single overall percentage relating the annual non-served energy to the total annual demand or broken up into time-of-day-related percentages (off-peak reliability, peak reliability, and so on). The per unit cost of non-served energy (CNSE) is closely related to that of reliability. Since REM includes the cost of the non-supplied energy as an operation cost, the higher the CNSE the more reliable the design provided by REM will be.
- Demand profiles (critical and non-critical, demand growth rate). Following the classification of buildings, the demand for each building needs to be characterized. To design electrification solutions for non-electrified buildings it is necessary to estimate how much electricity each building might consume if it had access to electricity. Since the model will try to meet the specified demand at the lowest cost, more detail about demand at each load point is likely to influence the results. Once the demand profile is constructed, in REM it must be classified into one of two types: 1) essential or critical load (e.g., lighting) or 2) non-critical load (e.g., television).
- Network components (catalog of lines and transformers). Power capacity and cost characteristics are the most relevant parameters.
- Mini-grid generation components (catalog of

- PV panels, batteries, diesel generators, and power conversion equipment).
- Strategic decision-making. Inputs that are related to social aspects and the electrification business model.
- Administrative cost. This is the general management cost of the system, and it has different values for the different electrification modes, reflecting economies of scale aspects that depend on the size of the systems. These costs are calculated differently for off-grid and grid extension systems. In REM, the administrative cost of a system only depends on its number of consumers. The input parameters that REM requires to calculate this cost are the administrative cost of small and medium-size mini-grids, as defined by their number of consumers, and at the asymptote the administration per customer cost of the central grid.
- In an off-grid system, the administrative cost is approximated with an analytic expression, which is calculated with the input parameters just described. Specifically, the model uses an exponential function to ensure that the per-consumer administrative cost is a decreasing function of the number of consumers.
- The administrative cost of a grid extension is calculated with a constant per-consumer cost (it does not depend on the size of the system) equal to the input parameter assigned to a large mini-grid. This ensures that the administrative cost of a grid extension is always lower than the administrative cost of a mini-grid.
- CNSE. REM is a cost-driven tool, so the lack of quality/reliability of the power supply must be translated to cost (it may also be imposed as a constraint in the case of mini-grids). CNSE is the cost to consumers of energy that is not served. CNSE represents the cost (i.e., the loss of utility) incurred by consumers when there is no electricity at a time when they are planning to use it. The value of the loss of utility depends on the time of the day, the activity being performed at that time, and the economic status of the customer. REM tries to capture this reality with just two values for CNSE, one for the essential load and another for the nonessential load. There could be multiple ways of estimating a value for CNSE. One of them is to adopt – as a proxy – the cost of an alternative energy solution (e.g., kerosene) that might be used when electricity is unavailable for some of the uses that it can provide. When it comes to calculating the CNSE, REM applies a different modeling procedure to deal with the cost of unserved energy with off-grid systems and grid extension designs. In off-grid systems, REM multiplies each amount of hourly demand (essential and nonessential) that is not met by the dispatch algorithm by the corresponding penalty. On the other hand, with grid extension designs REM assumes that the supply failures happen at random times and that all the supply is curtailed at that time. Therefore, the non-served energy is split homogeneously between essential demand and nonessential demand before multiplying these numbers by the corresponding penalties. For example, if the grid has a 90% reliability and the essential and nonessential demands in an hour are 5 kWh and 1 kWh then REM assumes that there are 0.5 kWh and 0.1 kWh of non-served essential and nonessential demand in that hour, respectively.
- Minimum mini-grid quality/reliability of power supply. In addition to representing reliability using CNSE, REM may include a minimum reliability target as a constraint in the case of mini-grids, expressed in terms of the percentage of energy served annually.
- A discount rate is needed to translate upfront investments to annuities. It is related to the business/investment models. Different rate values and different economic lifetimes for components can be set for different electrification modes.
- Grid connection criteria. REM can be made to include some social or political strategies that tend to favor some supply modes over others, for instance, to promote grid connection of customers that are not too far from the grid (and not far from other customers). Cost minimization can be, therefore, subject to constraints derived from energy policies.

Sensitivity analysis (qualitative)

- The different inputs described in the previous section are analyzed here concerning their influence on the expected results. The proposed classification and terms are respected, but two intermediate results are also used in the explanations, i.e., economies of scale and size.
- Economies of scale are the basis for local clustering decisions. They are also critical in the “detailed design” step. Since they may derive from different sources or inputs, they will be mentioned explicitly in the explanations.
- Size of clusters (or sub-systems), in terms of the number of buildings connected within the cluster. Economies of scale are closely related to size, but we will try to identify the two effects individually when possible.
- The expected results of REM are affected by the different input data elements in the following way:

Ground data

- Location of buildings (in terms of population density). Higher population density produces larger sizes of clusters. They will result in larger mini-grids (if far from the grid) and more grid extensions (if not far from the grid). The influence of size in grid extensions is closely related to the components of the network catalogs.

- Existing distribution feeders (in terms of distances to buildings). Part of the connection costs are proportional to distance, so systems of at least a minimum size and close to the grid will tend to become grid extensions (here the availability of small network components is critical).
- Energy resources (solar power availability, diesel cost if available and allowed). High solar power availability and low diesel prices favor mini-grids.
- Topography data (altitude map and penalized areas). Adverse terrain characteristics produce smaller systems and even isolated solutions.

The set of adopted assumptions

- Grid energy cost. Higher energy costs result in more mini-grids and fewer grid extensions (with small influence in isolated systems, except when they are special high-demand customers). The effect of this parameter on the solution is gradual and not strong if buildings-to-grid distances are large. If distances are short, then the impact of this parameter may be dramatic (since the connection cost thresholds depend mainly on transformers, instead of lines).
- Grid reliability. This parameter affects dramatically the presence of grid extensions if CNSE is significant since non-served energy is directly penalized by CNSE (critical and non-critical). In contrast with mini-grids, grid reliability is a user input that cannot be mitigated by extra investments.
- Demand profiles (critical and non-critical, demand growth rate). The profile of critical energy is important since its CNSE value is usually high. More critical energy means a higher cost of grid extensions (if reliability is not 100%). In mini-grids, it may just result in more reliable designs, but the cost may not be affected much, since non-served energy costs are replaced by generation costs. The effect of the demand growth rate is similar to the effect of smaller components in the catalogs (network and generation). Higher demands produce bigger sizes and better economies of scale in the system, and therefore they favor bigger mini-grids and more grid extensions. Per unit cost (\$/kWh) usually decreases as demand increases.
- Network components (catalogs of lines and transformers). Smaller and less expensive components tend to produce bigger mini-grids and more grid extensions since they allow more connections with the same savings.
- Mini-grid generation components. Smaller and less expensive components tend to produce bigger mini-grids and more grid extensions, due to the bottom-up clustering strategy (initial decisions are possible). Beyond that, what is relevant is the presence of economies of scale in generation components. Diesel generators have economies of scale, both in investment costs and operational costs (efficiency).

In the case of batteries and PV panels, in which big systems are made of many small components, economies of scale should be modeled explicitly in realistic terms. Economies of scale produce bigger mini-grids, and indirectly they even may produce more grid extensions (since large systems are more likely to be connected to the grid).

Strategic decision-making

- Administrative costs. They may have different fixed values for different electrification modes (grid extension or mini-grids) or also include per unit costs as a decreasing function of size, to reflect economies of scale in the administration of larger systems, for instance in fee collection tasks. The influence of economies of scale is quite relevant; as has been already stated, they favor big mini-grids and more grid extensions in the final solution. As these costs are estimated, they are reflected separately in the final solution.
- CNSE. CNSE should be set to a value bigger than the typical energy cost in the system. CNSE is closely related to grid reliability in the case of grid extensions since non-served energy is directly penalized by CNSE (critical and non-critical). In the case of mini-grids, the effect is not so dramatic, since non-served energy costs are replaced by generation costs. Also, in mini-grids, the use of CNSE as a reliability driver may be replaced (or coordinated) with the minimum reliability constraints (next input described).
- Minimum mini-grid quality/reliability of power supply. This constraint may be imposed in the case of mini-grids, in terms of the percentage of energy served. Despite the cost, the effect is to guarantee a minimum reliability level for every off-grid solution.
- A discount rate is needed to translate upfront investments to annuities. The effect is obviously to change the annual costs, imposing a shorter or longer recovery of the investment. Since different values may be set for different electrification modes, it may bias the final solution one way or another (grid extensions, mini-grids, or individual systems).
- Grid connection criteria. They may bias the grid connection of priority customers that are not too far from the grid (and not far from other customers) so that the effect on the final solution is directly predictable in qualitative terms. The quantitative effects are quite interesting, since they may be used to estimate the actual cost of the particular criteria applied.

C. User preferences for REM

Table 20 shows additional financial and economical parameters for Suriname's rural electrification plan.

Administrative costs indicate overall cost of managing the systems and may vary for different alternatives (grid extension, mini-grids and isolated systems) and depending on the number of users in each system (larger systems, like grid extension, will benefit from economies of scale compared to the management required for individual isolated systems).

The input parameters that REM requires to calculate this cost are the administrative costs per customer of a small, medium and large mini-grid as well as the number of consumers of a small and medium mini-grid.

The administrative cost per customer of a grid extension is calculated with a constant cost (does not depend on the size of the system), which is equal to the administrative cost per customer of a large mini grid. This ensures that the administrative cost of a grid extension is always lower than the administrative cost of a mini grid.

Parameter	Description	Value
Discount Rate (%), grid extension, mini grids, isolated systems		12%
Lifetime (years), grid extension	Expected amortization of grid investments	25
Lifetime (years), mini grid	Expected payback on mini grid investments (may be equivalent to that of the grid)	20
Connection cost(\$), grid extension	Cost of meters / protections / auxiliary lines... (per household)	142
Connection cost(\$), mini grids	Cost of meters / protections / auxiliary lines... (per household)	142
Labour cost O&M (\$/hour)	Operating and maintenance personnel cost per hour	6
Administrative costs grid extension (\$/year)	Billing / collection / customer service cost	8
Administrative costs isolated systems (\$/year)	Billing / collection / customer service cost (applicable in fee-for-service models)	10
Administrative costs mini grids (\$/year)	Billing / collection / customer service cost	10

Table 20 . Financial and economical parameters for REM.

D. Tracking tools

A tracking tool to follow the progress in energy access of the rural areas in Suriname is provided, based on key indicators.



GIS Tracking tool

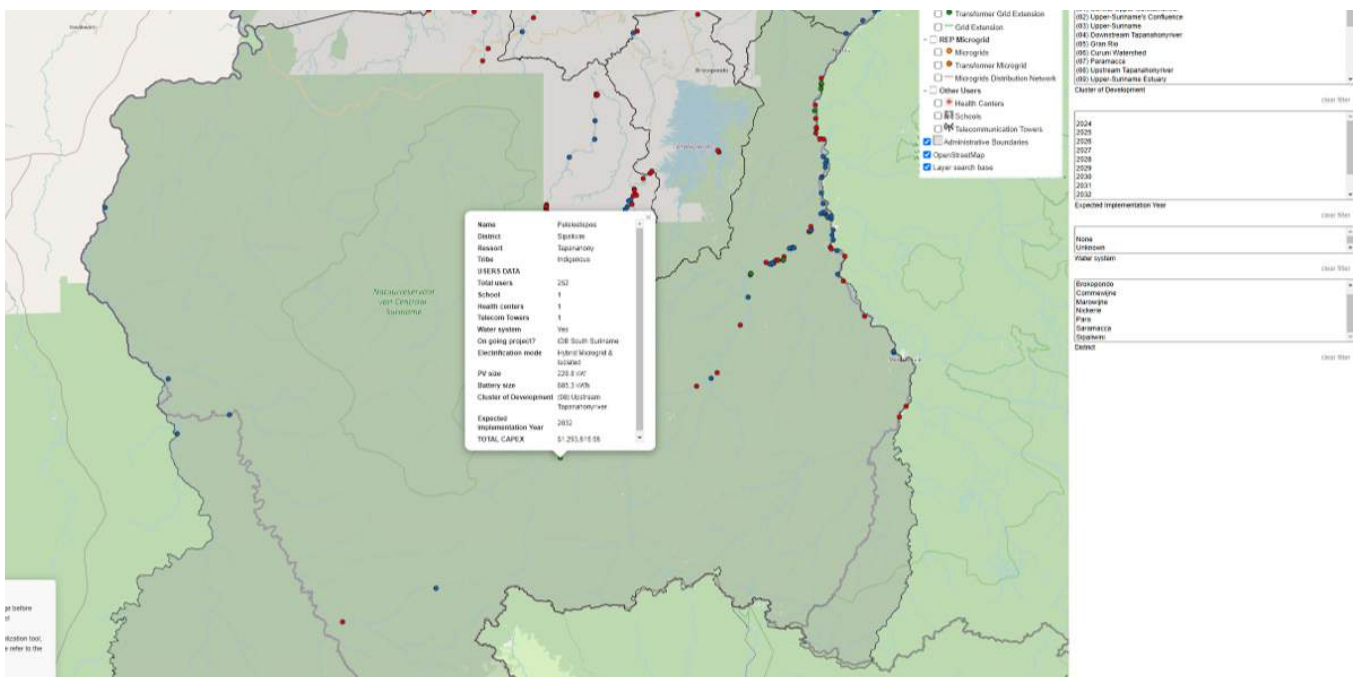


Figure 50. GIS tracking tool dashboard.

Excel Tracking tool

The dashboard in **Figure 38** is an instantaneous picture of the rural areas' electrification state in Suriname, and it serves the purpose of indicating the number of users to be electrified and the investment executed.

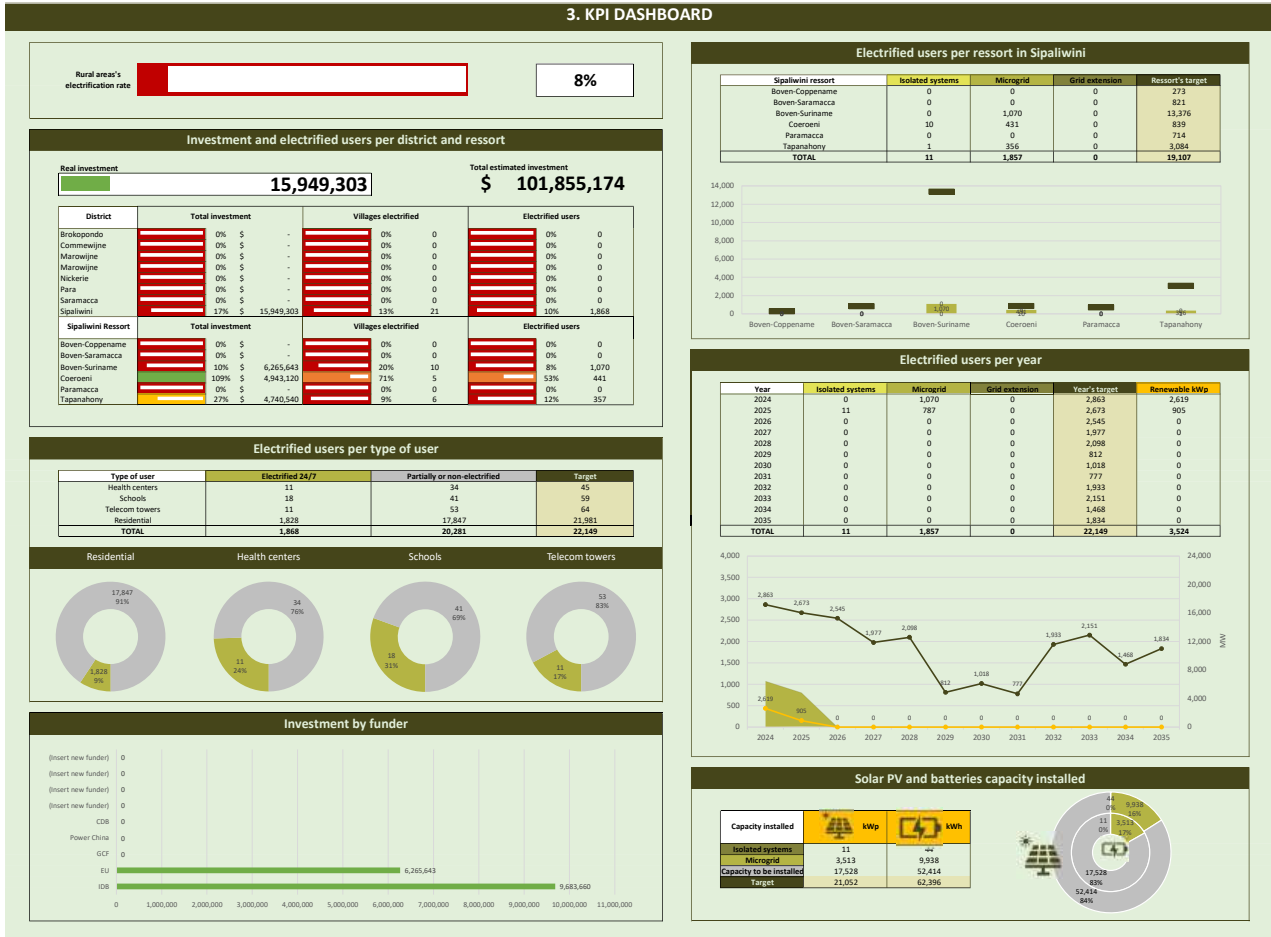


Figure 51. Excel tracking tool dashboard.

Dashboard panels description:

- a. Rural areas electrification rate: illustrates the electrification rate for rural areas in Suriname only, the 100% of the electrification will be achieved when all of the projects from the Rural Electrification Plan are completed.
- b. Investment and electrified users per district and resort: showcase the number of electrified users, electrified communities and investment executed per District and in the Ressor of Sipaliwini (since this is the district where more of 80% of the rural communities are located). It also indicates the total executed investment regarding the estimate investment in the Rural Electrification Plan.
- c. Electrified users per type of user: represents the number of users electrified per type (residential, school, health centers and telecommunication towers), as well as the final target or the total number of users expected to be electrified according to the Rural Electrification Plan.
- d. Investment by funder: this bar graph adds up the investment by funder or source of resources of the projects completed along the next years.
- e. Electrified users per resort in Sipaliwini: describes the electrified users per electrification mode only for Sipaliwini ressort.
- f. Electrified users per year: illustrates the progress of electrified users per electrification mode per year covering a timeframe of 7 years (2024-2030). It also showcases the solar PV renewable energy capacity installed.
- g. Solar PV and batteries capacity installed: represents the solar PV renewable energy and batteries capacity installed.

Sheets description:

1. Rural Electrification Plan: list of proposed projects to electrify rural areas in Suriname according to the Rural Electrification Plan.
2. Developed projects: list of projects developed to electrify rural areas in Suriname according to the Rural Electrification Plan.
3. KPI Dashboard: key performance indicators illustrates the current state of rural areas electrification in Suriname.

Fields description:

Field	1. Rural Electrification Plan	2. Developed projects	Description
Code	X	X	Code to identify each community.
Name	X	X	Name of the community (village or camp).
District	X	X	District to which the community belongs.
Ressort	X	X	Ressort to which the community belongs.
Camp/Village	X	X	Indicates if the community is either a village or a camp.
Zone	X	X	Geographical coordinates of the community.
Hemisphere	X	X	
Coordinates X	X	X	
Coordinates Y	X	X	
Tribe	X	X	Tribe to which the community belongs.
Total users	X	X	Number of residential users of the community.
School	X	X	Number of schools in the community.
Health centers	X	X	Number of health centers in the community.
Telecom Towers	X	X	Number of telecommunication towers in the community.
Water system	X	X	Indicates if the community has a water system.
Electricity source in 2023	X	X	Indicates the current electricity source of the community, if existing.
On going project?	X	X	Indicates if there is an on-going project to electrify the village or if there is any interest by EBS.
REP Electrification mode	X	X	Indicates the electrification mode proposed by the REP (grid extension, mini grid or isolated system).

Field	1. Rural Electrification Plan	2. Developed projects	Description
1 project for 2 villages (Cod)	X	X	Indicates if the project proposed by the REP covers more than one community.
Isolated systems users	X	X	Number of users electrified by isolated systems (including schools, health centers and telecommunication towers).
PV size (kW)	X	X	Total solar PV capacity (not per user) of users electrified by isolated systems.
Battery size (kWh)	X	X	Total battery capacity (not per user) of users electrified by isolated systems.
CAPEX	X	X	Total investment (not per user) for isolated systems projects.
Mini grid users	X	X	Number of users electrified by mini grids (including schools, health centers and telecommunication towers).
PV size (kW)	X	X	Total solar PV capacity of mini grids.
Battery size (kWh)	X	X	Total battery capacity of mini grids.
LV Grid extension (km)	X	X	Total low voltage line extension in km of mini grids.
MV Grid extension (km)	X	X	Total medium voltage line extension in km of mini grids.
CAPEX	X	X	Total investment (not per user) for mini grids projects.
Grid extension users	X	X	Number of users electrified by grid extensions (including schools, health centers and telecommunication towers).
LV Grid extension (km)	X	X	Total low voltage line extension in km of grid extensions.
MV Grid extension (km)	X	X	Total medium voltage line extension in km of grid extensions.
CAPEX	X	X	Total investment (not per user) for grid extensions projects.
School		X	Number of schools electrified in the community.
Health centers		X	Number of health centers electrified in the community.
Telecom Towers		X	Number of telecommunications towers electrified in the community.
Expected Implementation year	X	X	Proposed year and actual year of implementation of projects according with REP.

Field	1. Rural Electrification Plan	2. Developed projects	Description
Funder		X	Funder of the project to electrify the community.
Program		X	Program of the project to electrify the community.
Cluster of development	X	X	Number of cluster to which the community belongs.
Total users		X	Total number of users of the community.



