THE WORLD BANK

ESMAP
Energy Sector Management Assistance Program

KARTOZA
OPEN SOURCE GEOSPATIAL SOLUTIONS

FINAL REPORT

Preparation of a Spatial Data Infrastructure and Visualisation Tool of Geo-Spatial Electrification Plan for the Government of Somaliland

Dear Funders and Colleagues,

We are pleased to provide you with this final report for the project “Preparation of a Spatial Data Infrastructure and Visualisation Tool of Geo-Spatial Electrification Plan in Somaliland”. In partnering with the World Bank and ESMAP, we provided an ensemble team for this project with expertise in open source geospatial application development, training and electrification planning. The result of the collaboration between project partners and stakeholders is a least-cost electrification model for Somaliland, an SDI (Spatial Data Infrastructure, Figure 1, top) and the SEP, the electrification modelling platform (Figure 1, bottom) for visualising the model results. This platform aims to facilitate the work taking place to ensure that access to electricity in Somaliland is ubiquitous.

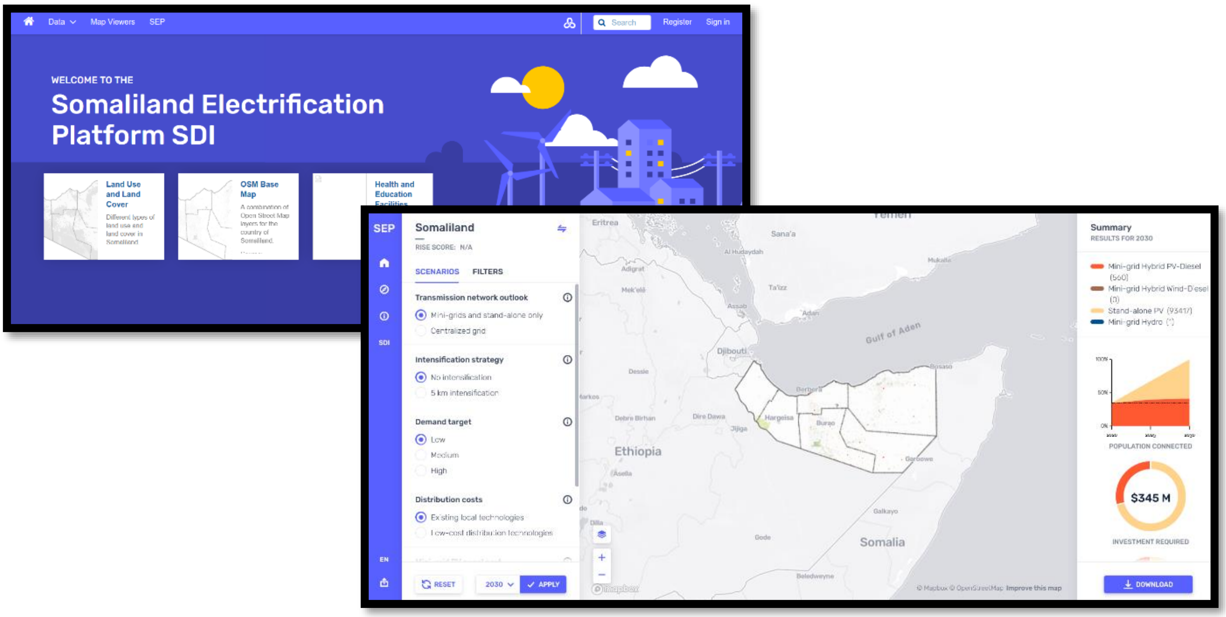

Figure 1 - The Somaliland SDI (top) and SEP (bottom)

Contained within this report you will find the details of the project and its completion, with input from our team as well as the World Bank, ESMAP, and the Ministry of Energy and Minerals (MoEM). We trust you will find the details provided within this report in good order.

With Kind Regards

Tim Sutton (Director, Kartoza)

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1 INTRODUCTION

1.1 ACKNOWLEDGMENTS

This report was written by project leads at Kartoza, with significant contributions from Nicolina Lindblad (World Bank),Alexandros Korkovelos (World Bank / ESMAP), and Guled Ahmed (SEAP Technical Expert). The project and its outcome benefited greatly from valuable comments and suggestions from our esteemed colleagues from the Government of Somaliland. We wish to thank these organisations for the opportunity to collaborate on this project, and are pleased to present the following report.

1.2 INTRODUCTION TO KARTOZA

KARTOZA
OPEN SOURCE GEOSPATIAL SOLUTIONS

We are Free and Open Source GIS (FOSSGIS) Service providers, providing a global service to individuals, companies and governments around the world who are looking to leverage the power of the Free Software movement to solve geospatial problems. We have a proven track record in precision agriculture, disaster risk reduction, biodiversity information systems and many more. We offer the following core services:

Training: We provide corporate training in the use of FOSSGIS such as QGIS, PostgreSQL/PostGIS and GeoServer. We also develop training materials and provide educator training to foster the study of GIS and geospatial technology at schools and universities.

Deployment and support: We provide services to help organisations deploy and maintain FOSSGIS systems within your organisation. This includes PostgreSQL/PostGIS databases, Linux based servers, QGIS on desktops and servers, Mapserver, GeoServer, GeoNode and many others.

Software development: We provide bespoke services for the development of custom solutions to meet business needs. These include desktop, web and mobile application development using FOSSGIS. Our web application development services are focussed on applications that have a geospatial component where we use technologies such as GeoDjango, OpenLayers and PostGIS.

Kartoza has been instrumental in the development of various high profile Open Source geospatial projects. We contribute to, and provide project leadership in, QGIS (http://qgis.org), InaSAFE (http://inasafe.org) and a large number of different in-house developed Open Source projects as can be seen in our GitHub repository at http://github.com/kartoza.

We value diversity and our team is made up of developers and support staff from South Africa, Portugal, Indonesia and Tanzania. Our offices are based in South Africa. Visit our website at https://kartoza.com.

1.3 INTRODUCTION TO ESMAP

The World Bank's Energy Sector Management Assistance Program, ESMAP, is a partnership between the World Bank and partners to help low and middle-income countries reduce poverty and boost growth through sustainable energy solutions. ESMAP's analytical and advisory services are fully integrated within the World Bank's country financing and policy dialogue in the energy sector. Through the World Bank Group (WBG), ESMAP works to accelerate the energy transition required to achieve Sustainable Development Goal 7 (SDG7) to ensure access to affordable, reliable, sustainable and modern energy for all. It helps to shape WBG strategies and programs to achieve the WBG Climate Change Action Plan targets. This includes the Geospatial Electrification Planning in the Africa Region project, which funds geospatial least cost-electrification planning for African countries, with the objective of supporting their energy access objectives.

1.4 CONTEXT

Somaliland is located in the Horn of Africa, with Djibouti to the Northwest, Ethiopia to the south and west, and Somalia to the south and east. The land area of Somaliland is approximately 176,119 square kilometres with 850 kilometres of coastline along the Gulf of Aden. As The Somaliland Health and Demographic Survey 2020 report indicated, Somaliland has a population of 4.2 million people.

Inequalities in electrification rates are noticeable within the country. As such, electric modelling and planning are of great importance to Somaliland. In response to the challenges of electricity generation in the country, lack of investment in the grid, and limited regulation, the Government of Somaliland (Government, GoSL) has implemented the Somaliland Electricity Project (SEP), with funding from the World Bank. This program is among many initiatives that are aimed at improving the access to electricity in the target urban, peri-urban, and rural communities in Somaliland. Specifically, this programme focuses on:

- Increasing access to modern energy solutions;
- Reducing market barriers to providing these solutions;

- Increasing resources for the GoSL and overall energy sector management.

Achieving sustainable development will be a crucial part of Somaliland's economic and social development. In order to facilitate the transitions needed for this, robust energy planning efforts need to be put in place. Reliable energy-related data are essential for electrification planning. Information concerning settlements' size and location, distance from existing and/or planned infrastructure (e.g. transmission network, power plants, and roads), economic activity, local renewable energy resources, etc. can convey useful information and help planners take the right decisions regarding the most effective pathway for electrification. However, it is usually the case that in countries where universal electrification is still to be achieved, such information is scarce and difficult to access.

The paucity of such information is one of the reasons hampering energy planning activities and electrification in currently unserved areas. This situation is gradually changing with the increasing availability of new data and analytical tools, especially in the field of geospatial analysis. Geographic Information Systems (GIS) and remote sensing techniques are openly available and can provide a range of location-specific information that has not been previously accessible. These, in combination with new open source modelling tools, have set up new ground in the field of electrification planning, accelerating progress towards achieving sustainable electric development.

Against this background, Kartoza together with the World Bank's Energy Sector Management Assistance Program (ESMAP) carried out the **Preparation of a Spatial Data Infrastructure and Visualisation Tool of Geo-Spatial Electrification Plan.** Using the Open Source Spatial Electrification Tool (OnSSET), ESMAP has developed least-cost electrification scenarios examining different investment needs in order to reach the goals of the project. These scenarios have all been deployed on the Somaliland Electrification Platform. Users of the platform have direct access to the results at different levels. The scenarios assess the effect of different variables on electrification potential.

This plan was developed in distinct phases: **inception** (where the project planning process was finalised and the technology platform was established), **pilot** (where an initial analysis was carried out) and **final analysis** (where, based on feedback from stakeholders, the model parameters and inputs were fine-tuned). The model results have been deployed on Somaliland Electrification Platform. Three open source applications were used in this project:

1. OnSSET: a GIS based optimization tool that has been developed to support electrification planning and decision making for the achievement of energy access goals in currently unserved locations. Available at: http://www.onsset.org

2. GeoNode: a web-based application and platform for developing geospatial information systems (GIS) and for deploying spatial data infrastructures (SDI). Available at: http://geonode.org

3. GEP Explorer: a web-based platform for exploring electrification scenarios. Available at https://github.com/global-electrification-platform/explorer.

1.5 SCOPE AND OBJECTIVE

The scope of the "Preparation of a Spatial Data Infrastructure and Visualisation Tool of Geo-spatial Electrification Plan" project was to accomplish the following:

- **SEP / SDI Platform:** This task required the preparation of a Spatial Data Infrastructure (SDI) relevant to the energy sector. Additionally, it was required to provide the development of a visualisation tool (the SEP) to host the open-source geospatial least-cost electrification model developed under the SEP project.

- **Server Hosting and Maintenance:** Hosting and maintenance services were required in order to support the long-term goals and success of the SDI.

- **Capacity Building and Implementation Arrangements:** Ultimately, the SDI should empower local users to gain insight into the analytics of the SDI. As such, it was required that training, resource assessments, and project management be provided to further this goal. The aim of the capacity building under this assignment was to familiarize Government staff with GIS, so that these staff can understand and create GIS methodology for the development of the SDI over time.

- **Reporting and Data Transfer:** Finally, it was required that all products be made available to the Government at the end of the project, including all required reports, elements of the SDI, and all underlying infrastructure for the visualisation tool. It is required that a workshop be orchestrated to present all findings and information in a forum style.

2 SPATIAL DATA INFRASTRUCTURE

2.1 OVERVIEW

Much of this project centred around the creation of a Spatial Data Infrastructure, or SDI. The core components of an SDI are highlighted in the diagram below.

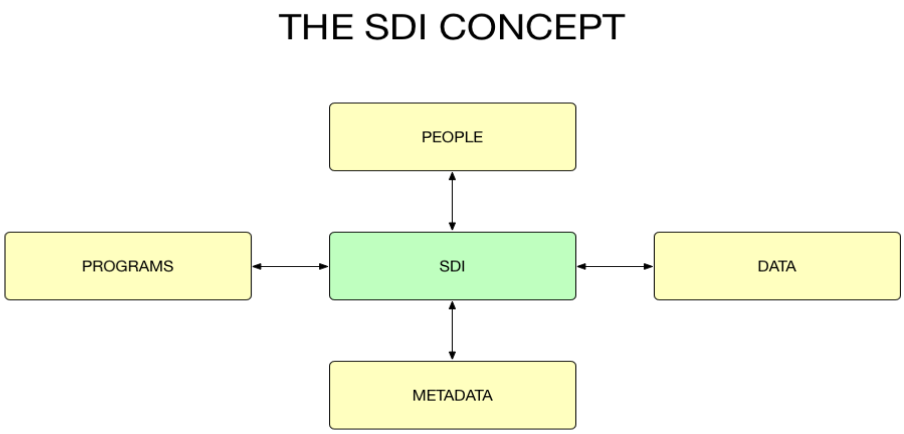

Figure 2 - The SDI Concept

A Spatial Data Infrastructure (SDI) seeks to support users with the provision of data, metadata, software and computational services to provide a productive and flexible environment for working with geospatial data. In an enterprise environment, the development of an SDI constitutes the foundations of the GIS department or group in your organisation. The Open Geospatial Consortium (OGC) provide a number of standards used by elements of an SDI. The FOSSGIS (Free and Open Source software for Geographical Information Systems) community has in turn provided various pieces of software for developing an OGC standards compliant spatial data infrastructure (SDI). In this section we briefly explain the core concepts and components of the SDI as relate to this project.

The spatial data repository. For storage of geospatial data, PostgreSQL and PostGIS (an extension to PostgreSQL that enables geospatial data to be stored and analysed within the database) provide an enterprise-ready platform. They run on all major platforms (Windows, Linux, Mac OS) and provide a data store for vector data, capable of providing for multiple concurrent users and hosting large volumes of data. PostGIS supports representation of features in both the OGC Simple Feature Specification or as true topology (where nodes and edges between adjacent features are only represented once in the data model). Although PostGIS is capable of storing raster data too, it is more usual to use a traditional file system-based approach for hosting raster data. For file-based storage, the GDAL library supports data access and transformation services of raster data, including enabling one to generate hierarchical tile mosaics (TMS) stores from source raster data

Metadata: In addition to a data store, it is important for an SDI to support the annotation and publication of geospatial data with standards compliant metadata in a metadata catalogue. This is referred to as the data catalogue service of the SDI. Typically, an SDI should publish data using ISO based institutional standards such as INSPIRE, ISO 19115 etc. made available by the Catalogue Services for the Web (CSW) standard. The CSW server provides tools to manage metadata for geospatial data sources, search that metadata and browse the related datasets using a web map viewer. Platforms such as GeoNode provide spatial data storage services and catalogue services in a single platform.

Spatial Data Services: There is a need to direct users to the data itself after it has been discovered in the catalogue. This functionality is provided by the spatial data service component of an SDI. GeoServer is used by GeoNode for data publishing. These spatial data servers make data stored in the spatial data repository available via a number of standards-based protocols: The web feature service (WFS) for serving vector feature data, web coverage service (WCS) for serving raster coverages and the web mapping service for publishing ready-to-consume cartographic renderings of one or more datasets.

Desktop Client Systems: With the above elements in place, a key remaining element is to leverage the SDI to provide GIS services to users via desktop and web-based GIS applications. For desktop users, there are a number of mature, feature rich GIS applications such as QGIS.

Web Based Client Systems: For cases when users need to discover and access the SDI via a web browser, the FOSSGIS Community have developed a number of useful applications. Probably most well-known are the JavaScript libraries OpenLayers and Leaflet. The former provides an extremely versatile set of functionalities for making richly functional web applications. Leaflet, on the other hand, aspires to be a very lightweight JavaScript GIS browser that can be extended via plugins as needed. These are both build-your-own tool kits, though there are a number of ready to run web applications to serve many different use cases.

The technical components of an SDI are not the only consideration when performing an SDI implementation. Further thought needs to be applied to the integration of the SDI with existing systems and give due consideration to institutional factors such as security, data sharing policies, network topology and technical opportunities and limitation that might impact the roll out of an SDI.

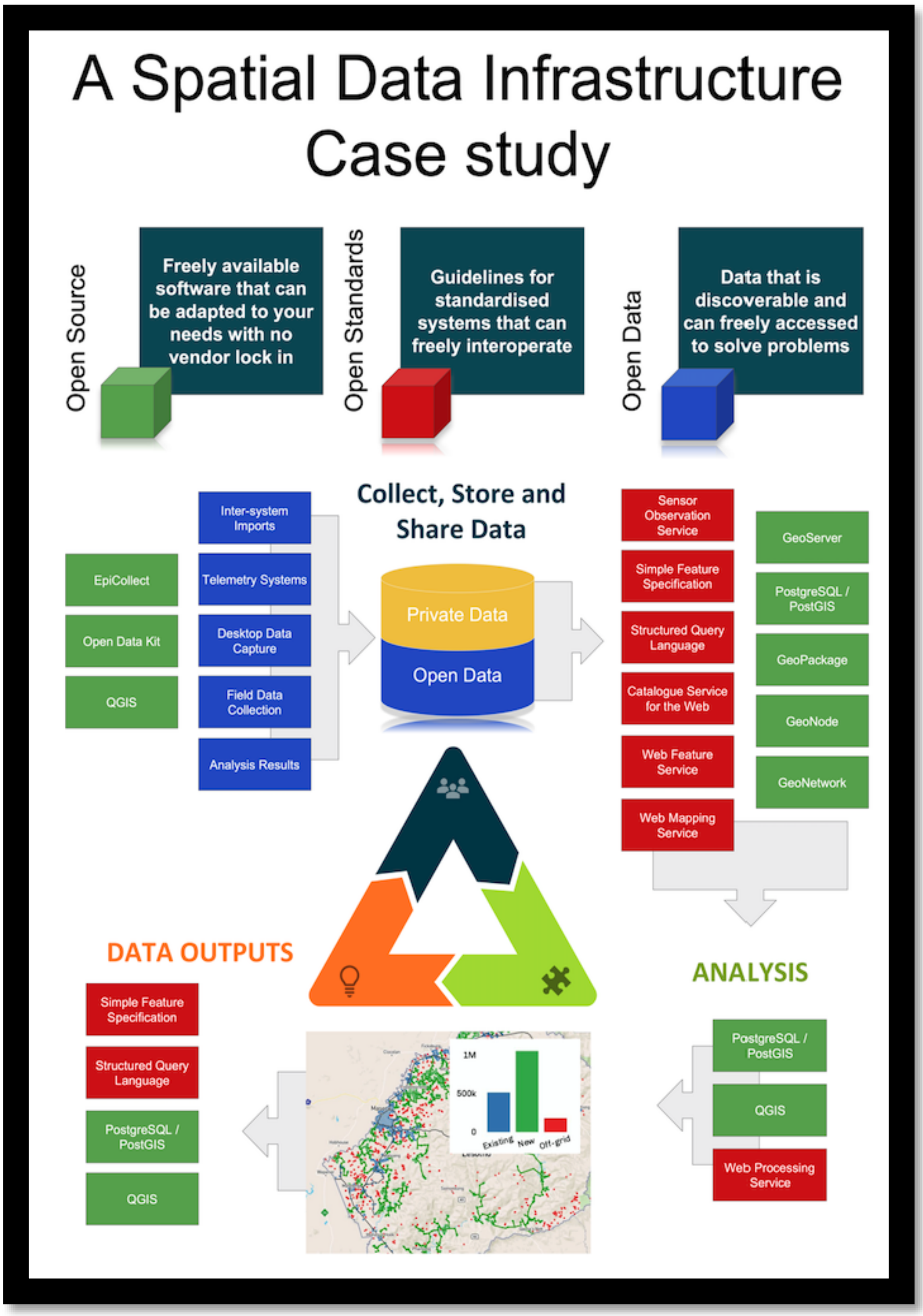

Figure 3 - SDI Case Study

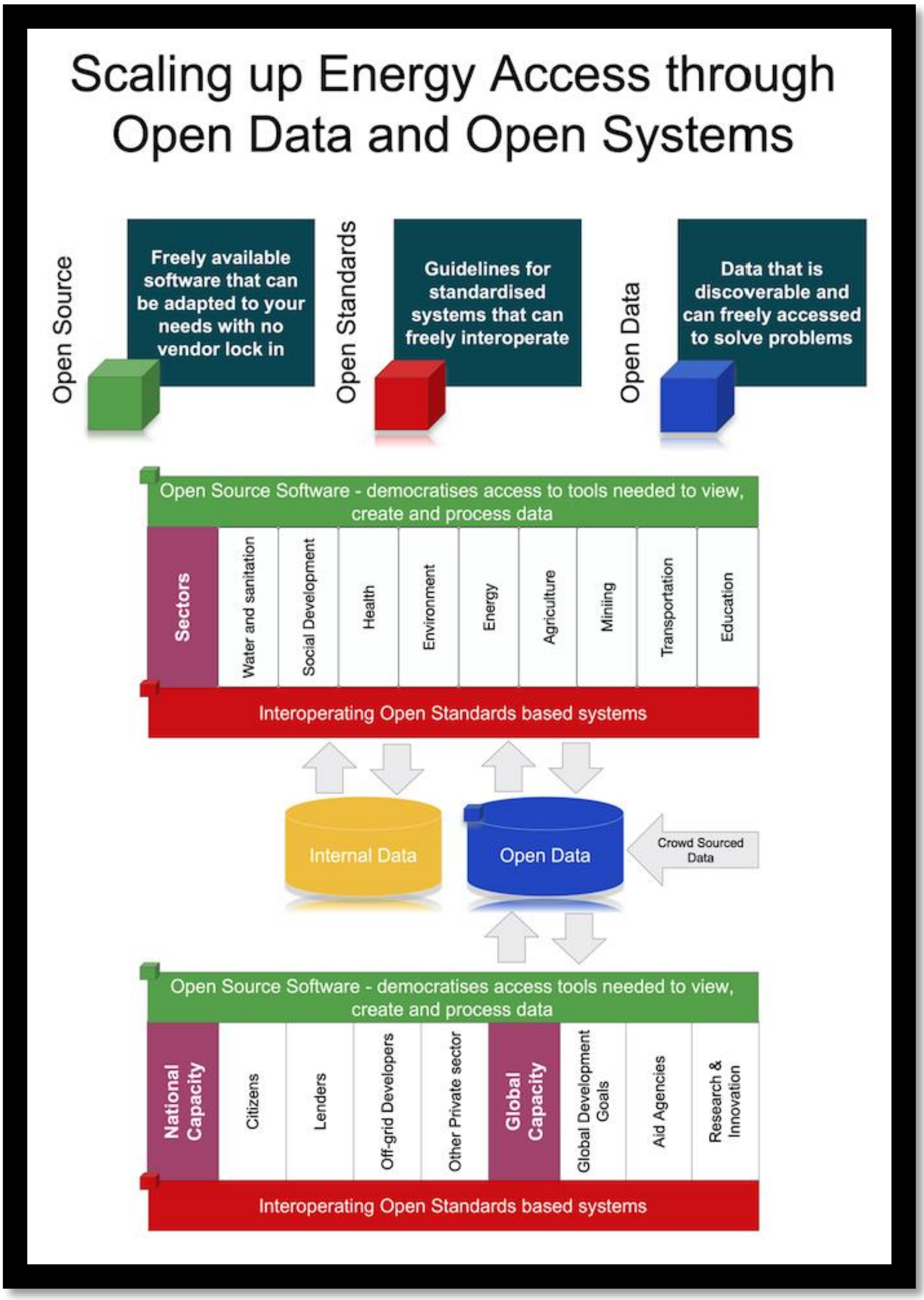

Figure 4 - Open Data Systems

2.2 GEONODE AS AN SDI

Our base platform for the SDI is GeoNode (http://geonode.org). The Geonode-based SDI Kartoza created for the Government of Somaliland has the following features:

1. A web-based home page, where the user can navigate to the SDI or to the SEP:

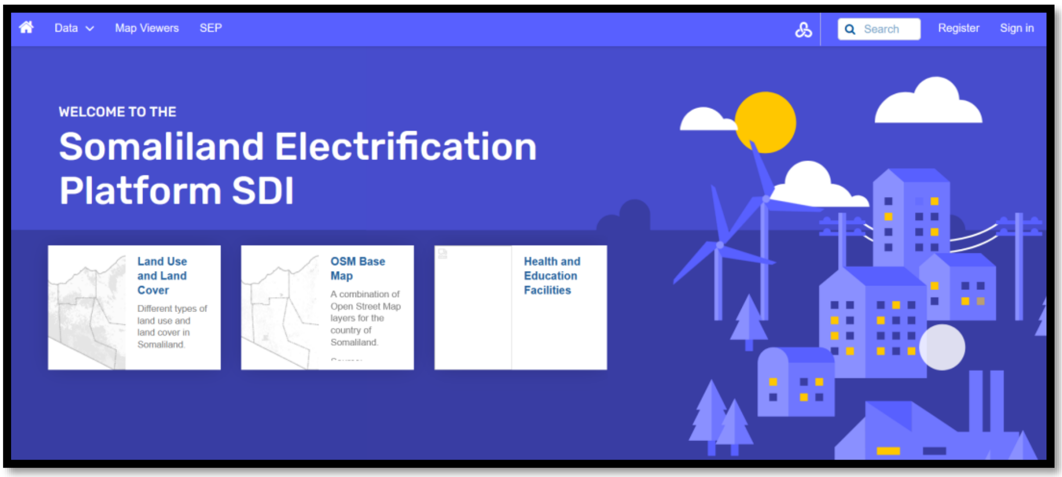

Figure 5 - The SDI home page

2. Once the user navigates to the SDI a layer browser page appears, where users can explore all layers available:

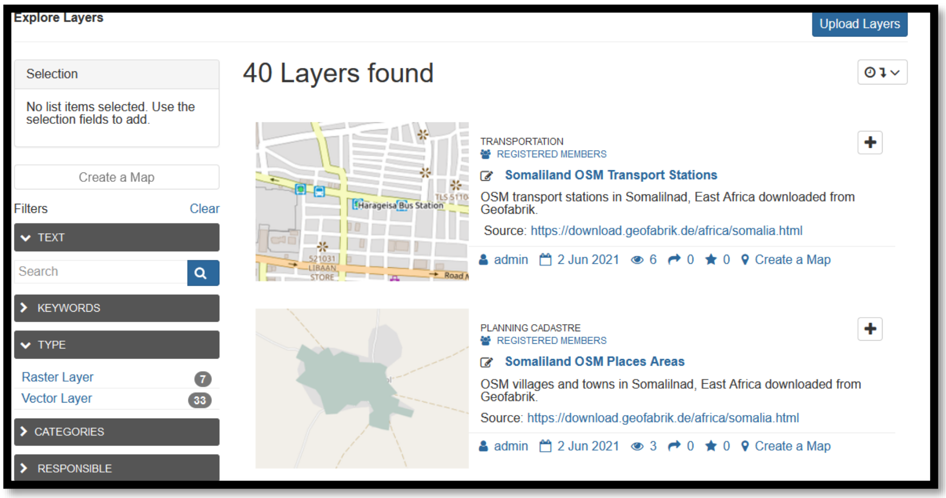

Figure 6 - Layer Browser Page

3. There is also a map browser page, where the user can browse maps that have been created as compilations of available layers:

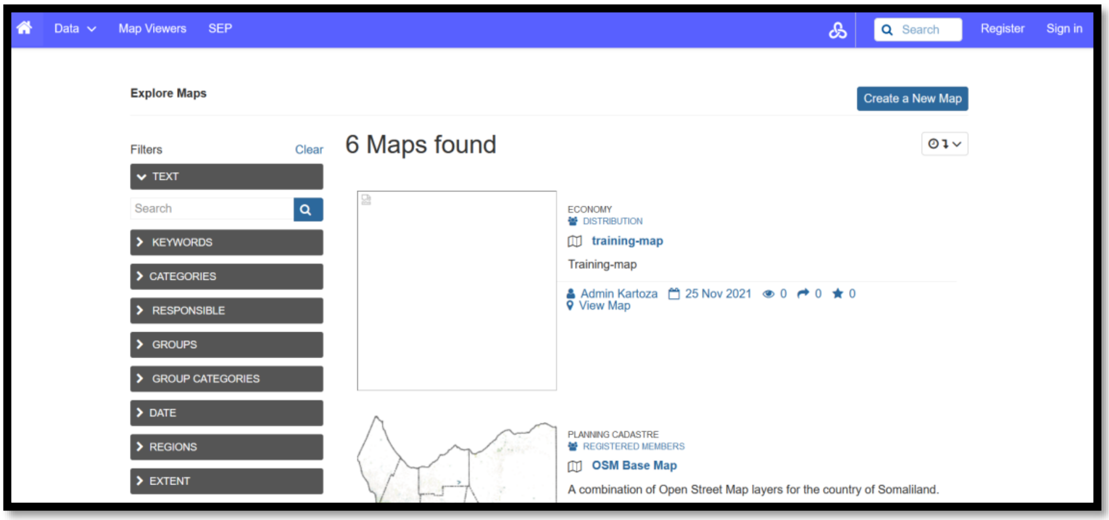

Figure 7 - Map Browser Page

4. The SDI supports advanced functionality as well. The database underlying the SDI contains spatial data that can be accessed from desktop GIS such as QGIS if needed. This will be restricted to privileged users. The user can connect to the web services published by GeoNode, as per the example shown below:

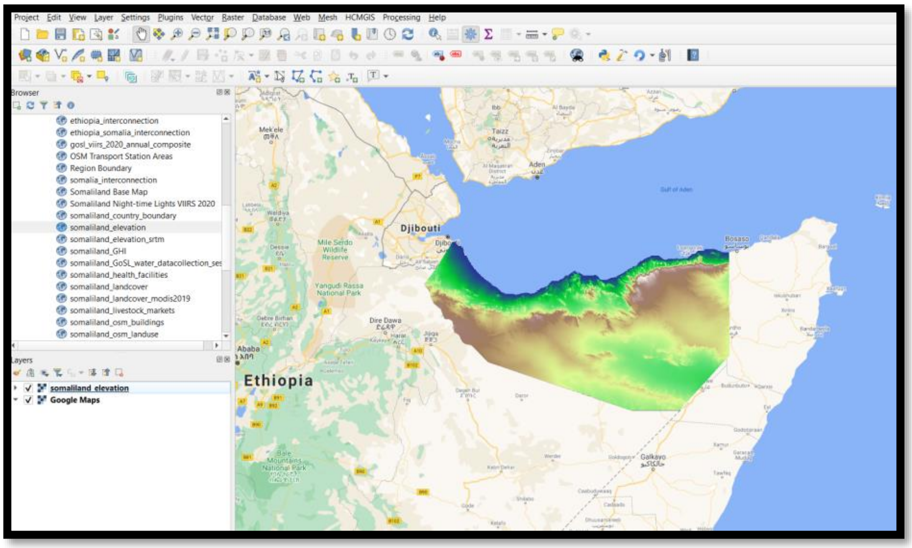

Figure 8 – Connecting to services in QGIS

QGIS also provides tight integration with the SDI via the GeoNode data browser which Kartoza developed previously for the World Bank. For advanced users, they will be able to connect to GIS data utilising the desktop GIS application QGIS. From there they will be able to perform local geospatial analysis with the data and generate new products. QGIS provides a large range of analysis tools that can be used for this purpose.

2.3 LAYER AVAILABILITY

The following layers are available within the SDI for users to view, add to maps and, for more advanced users, connect to in desktop GIS software such as QGIS.

Currently Available Layers in the SDI:

- GoSL VIIRS 2020 Annual Composite 2
- Tec Elafwayn Distribution Line
- Boram 11kV Tec Distribution Line
- Sepco Distribution Line
- Berbera 11kV Distribution Line
- Aloog 11kV Distribution Line
- Background Layer for the basemap
- OSM Buildings
- Hargesia Electrical Power Lines
- Night-time Lights VIIRS 2020
- Land Cover MODIS Land Cover Type 2019 500m
- Elevation SRTM 30m
- OSM Transport Stations
- OSM Towns and Villages
- OSM Waterways
- OSM Fresh Water Surfaces
- OSM Land Use
- OSM Roads
- OSM Natural Land Features
- OSM House of Worship (Polygon)

- OSM House of Worship (Points)
- OSM Places of Interest/Service
- OSM Transport Station Areas
- OSM Place Names
- Somalia Interconnection
- Ethiopia-Somalia Interconnection
- Ethiopia Interconnection
- ESP Mini-grids
- Health Facilities
- Education Facilities
- Rivers
- Landcover
- Wind Speed
- Elevation
- Global Horizontal Irradiation (GHI)
- Small Scale Hydrological Power
- GoSL VIIRS 2020 Annual Composite
- Travel Time
- Livestock Markets
- UNHCR Refuges IDP
- GoSL Water Data Collection SESRP
- OSM Poverty Rate
- Road Network
- Country Boundary
- Region Boundary

2.4 TRAINING RESOURCES

Kartoza conducted training with colleagues from the Government of Somaliland on the SDI on several occasions throughout 2021. These trainings have been recorded and are available any time via this Youtube playlist. This Youtube playlist does not appear on Youtube's search feature and is only available to those with the link to the playlist. This playlist will take users through the training that Kartoza conducted in 2021, allowing for users to become familiar with the basics of the SDI and SEP, along with the more advanced functionalities of these platforms.

3 ELECTRIFICATION PLATFORM

The Somaliland Electrification Platform (SEP) was developed upon the principles of openness and transparency and aims to enable reusability, replicability and reproducibility of embedded processes and data for geospatial electrification studies. Therefore, both the frontend and backend infrastructures are open source. This enables anyone interested in the tool to modify and use any component of its infrastructure. The platform enables the user to visualize in detail the results for all electrification scenarios developed, to be able to examine different electrification strategies and sensitivity of key parameters. The orchestration of this code is available at https://github.com/Somaliland-Electrification-Platform. The backend GEP source code is available here https://github.com/kartoza/global-electrification-platform-data-service (including our customisations) and the code for the frontend GEP site (including our customisations) is here https://github.com/kartoza/global-electrification-platform-explorer. The following topics will describe the electrification platform at a high level, with more in-depth information presented in Section 4.

3.1 FILTERS ON THE PLATFORM

On the platform the user has the option of narrowing down (filtering) the results of each electrification investment scenario based on different characteristics. This is achieved by applying one (or more) of the following filters:

- Cluster Population
- Least cost electrification technology option
- Region
- Final electricity demand
- Distance to closest transmission and distribution line

- Distance to closest main road
- Distance to closest urban centre
- Electrification status in 2020
- Water point (yes/no)
- Health facility (yes/no)
- School (yes/no)
- Cost per connection
- Total buildings
- New connection

3.2 RESULTS ON THE PLATFORM

The user has the option to view results for each scenario using:

- Transmission network outlook
  - Mini-grids and stand-alone only
  - Centralized grid
- Intensification strategy
  - No intensification
  - 5 km intensification
- Demand target
  - Low
  - Medium
  - High
- Distribution costs
  - Existing local technologies
  - Low-cost distribution technologies
- Mini-grid PV panel cost
  - Low
  - High
- Diesel Cost
  - Low (0.5 USD/litre)
  - High (.8 USD/litre)

When the scenario or filter is altered on the platform, different results will be displayed. In the middle of the screen a map of clusters is visualized. Every cluster has a specific colour, corresponding to the least-cost technology option in that cluster. On the right-hand side of the screen there are summaries for the entire country for the selected scenario. These summaries include the population connected to each technology configuration as well as the investment and added capacity needed for each technology configuration. Specific clusters also be selected by clicking on them. This will show a popup window displaying key information for that specific cluster, as seen in the second screenshot below. Finally, there is also the option to select different layers from the SDI to display over the electrification scenario results (see the final screenshot of this section).

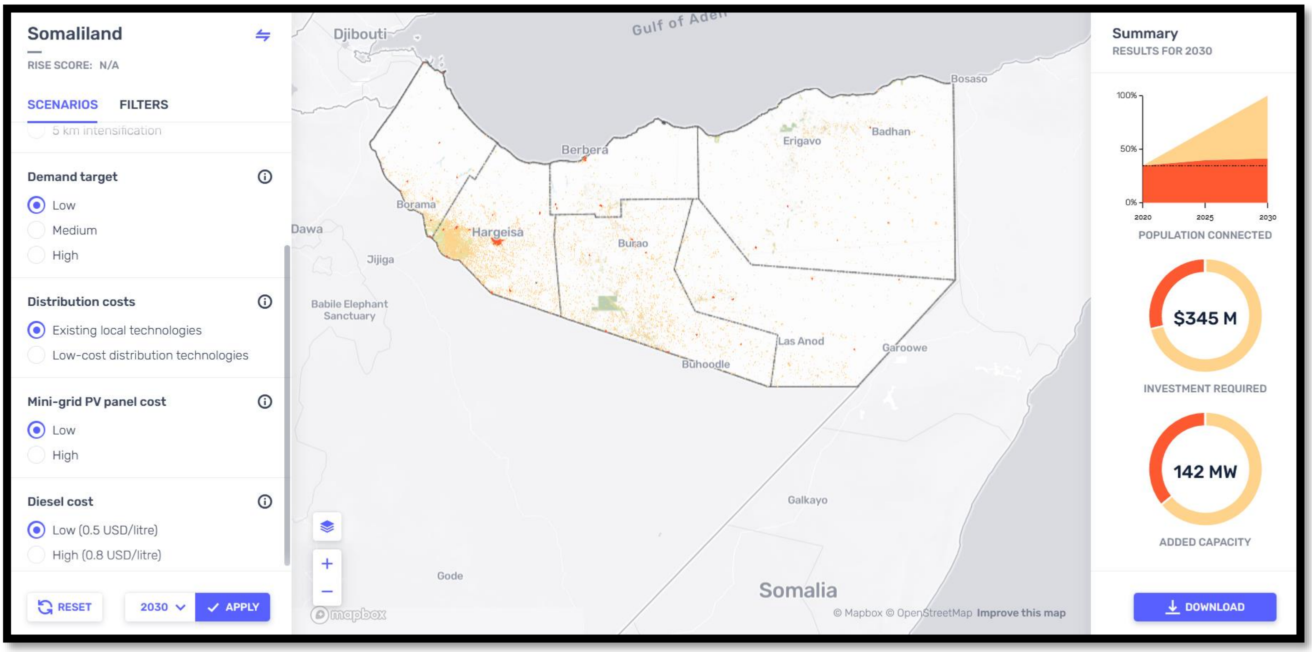

Figure 9 - The SEP with a certain scenario identified, resulting in clusters of different colours and scenario details listed on the right.

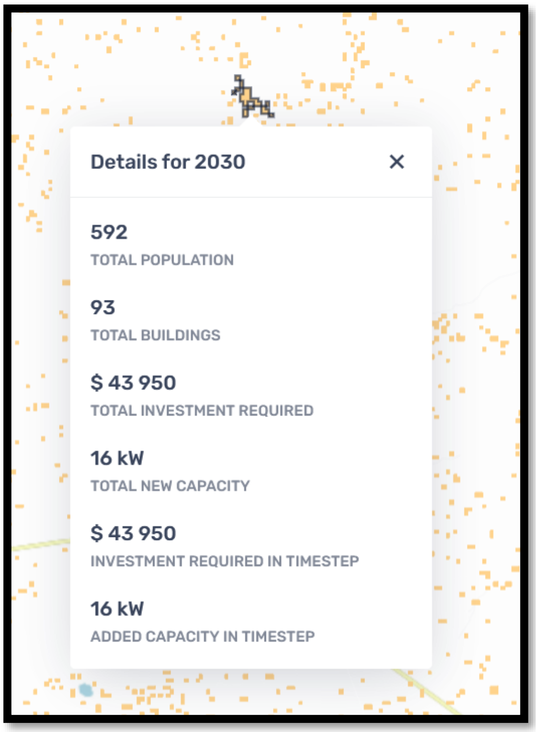

Figure 10 - The pop-up view for each cluster when clicked on.

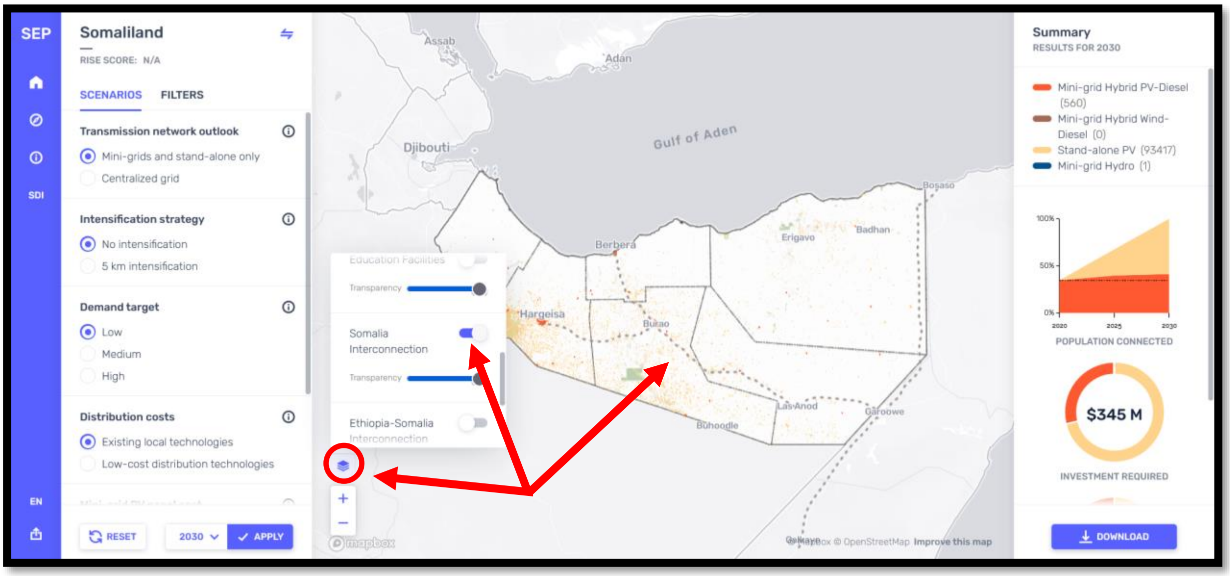

Figure 11 - The layer selection tool, where layers from the SDI can be visualised with the electrification scenario results.

4 GEOSPATIAL ELECTRIFICATION ANALYSIS

The entirety of Section 4 was composed and written by Nicolina Lindblad (World Bank), Alexandros Korkovelos (ESMAP/World Bank), and Guled Ahmed (SEAP Energy Technical Expert).

4.1 OVERVIEW

The Somaliland Electrification Platform (SEP) is an online interactive interface that provides access to selected inputs & outputs related to electrification planning in Somaliland. The SEP is the result of a comprehensive geospatial analysis, undertaken to examine different options for electrification in Somaliland between 2020-2030. It also aims to provide useful data, information and insights to support robust decision-making in the country's electricity sector over the next decade. As part of the project, the consultants have used OnSSET to generate 96 electrification investment outlooks for the country. All outlooks aim at achieving 100% electricity access by 2030. This document provides a brief description of the key input parameters & assumptions used to develop and customize the geospatial least-cost electrification scenarios for Somaliland.

4.2 RESOURCES

- Link to SEP and SDI here
- Link to code here
- Link to assumption spreadsheet with sources and explanations here

4.3 INPUT DATASETS

It should be noted that the least-cost electrification analysis for Somaliland was primarily based on datasets available through the Global Electrification Platform (GEP). That is, datasets regarding the road network, global horizontal irradiation, wind speed, land cover, hydropower potential, traveling time to nearest town, elevation and GDP distribution, were based on the work undertaken for the GEP. A detailed list of datasets with their sources can be found here[1].

Some additional layers that are important for the analysis, have however been collected in collaboration with the local counterparts in Somaliland and/or generated from scratch by the team using shared information. Those are presented below.

Note! Most datasets are available through the project's SDI (see Resources above)

[1] The list is regularly updated based on best available data; a more detailed list is also available here.

4.3.1 ADMINISTRATIVE BOUNDARIES

There is no official international source delineating with precision the administrative boundaries of Somaliland. Therefore, the team has worked with the Somali counterparts to digitize an existing map and generate an up-to-date spatial layer of administrative divisions for the country.

4.3.2 POPULATION CLUSTERS

This layer contains the settlements identified in Somaliland. The layer is a product of spatial processing of the *"WorldPop peanutButter"* layer. The methodology has been developed by KTH university and is presented in more detail in this academic paper. The result layer has indicated 93978 settlements in Somaliland. Both input datasets and code to generate the population clusters are open source and available at the project's GitHub repository (see Resources).

4.3.3 NIGHT-TIME LIGHTS

This layer indicates light intensity at night. In this analysis we have updated the layer used in GEP by using VIIRS 2020 annual composite. The dataset indicates the average, annual, cloud-free night-time light intensity per pixel, and was used to identify and calibrate electrified population in the base year.

4.3.4 POWER INFRASTRUCTURE

Spatial information about the power infrastructure – and more specifically the location of existing ESPs - were retrieved by GoSL. In the analysis we have used data for 44 existing mini grids throughout the country. Information regarding the potential routing of the HV backbone interconnector between Somaliland and Ethiopia was based on data retrieved from the *"Electricity Transmission and Distribution Grid Map in Africa"* available by the World Bank at energydata.info.

4.3.5 HEALTH FACILITIES

Here the team used the SARA survey dataset together with data shared by the GoSL to identify the status of existing health facilities in the country. The survey dataset did not however contain coordinates of the location. Therefore, the team geotagged the health facilities based on their name, using a Levenshtein Distance based algorithm in python and OSM Nominatim. The process yielded **348 health facilities** that were geotagged and used in the electrification analysis for Somaliland.

4.3.6 EDUCATION INSTITUTIONS

The datasets used here was provided to the team by the GoSL and were combined with open-source data available at UNICEF's database. The survey dataset did not however contain coordinates of the location. Therefore, the team used a similar method (described above for health facilities) to add coordinates to each location. The process yielded **730 education facilities** that were geotagged and used in the electrification analysis for Somaliland.

4.3.7 OTHER SOCIO-ECONOMIC & INFRASTRUCTURE DATASETS

Datasets depicting other infrastructure and/or socio-economic status have also been provided to the team by the GoSL and/or collected by other regional initiatives. Those include location of water points, location of refugee camps and Internally Displaced Population (IDP) and location of markets. Those did not impact the results of the analysis but allow filtering out results on the SEP to identify areas (or settlements) of social interest.

Finally, it should be noted that as part of this project the team has used the Digitize Africa dataset to identify the distribution of structures in Somaliland. The dataset was used to count the number of buildings in each settlement. Note that this dataset is proprietary[2] and was provided by the World Bank for the purposed of this project.

4.4 KEY INPUT PARAMETERS/ASSUMPTIONS

- **Goal:** National least cost plan for achieving 100% electricity access by 2030
- **Modelling years:** 2020, 2025, 2030
- **Population in the start year (2020):** 4 200 000 people
- **Annual population growth:** 2.9%
- **Population in end year (2030):** 5 600 000 people
- **Urbanization ratio:** 54.1% (45.9% is considered rural or peri-urban population)
- **Electrification rate in start year (2020)[3]:** 35% national |80% urban | 2% rural
- **Average household size:** 6.5 urban | 5.6 rural
- **Intermediate electrification target (2025):** 67.5%
- **Annual grid connection limit:** None
- **Annual grid capacity expansion limit:** None
- **Prioritization method (for 2025):** Lowest investment cost per capita

A few critical categories of parameters are described in higher detail below:

[2] Note that an open access alternative is available in https://sites.research.google/open-buildings/

[3] The decision regarding which settlements are electrified in the start year, was based on most up-to-date data on existing mini-grids (Electricity Supply Providers – ESPs) and satellite imagery indicating lights at night. Population electrified by off-grid systems in the base year is considered negligible and not included. That is, all electrified population in the start year is assumed to get electricity from existing ESPs.

4.4.1 RESIDENTIAL DEMAND TARGETS[4]

Residential demand targets were set for urban and rural settlements respectively. The range of demand targets is presented below; settlements may receive different values within that range depending on the scope of the electrification scenario.

- **Urban settlements:** 300-1500 kWh/household/year (Tier 3 – Tier 5)
- **Rural settlements:** 60-450 kWh/household/year (Tier 1 – Tier 3)

Note! The total residential demand changes based on the targets in each scenario. The total electricity requirement for electrification of residential loads was estimated to range between 285.9-703.4 GWh in 2030.

4.4.2 DEMAND FOR HEALTH FACILITIES

Electricity demand for health facilities was based on the PoweringHealth tool. Based on that tool, power demand was defined for four types of health facilities:

- **Type 1:** Health Post, No Inpatient (~4 emergency beds) with ~2080.5 kWh/year
- **Type 2:** Health Center (~14 beds) with ~5073.5 kWh/year
- **Type 3:** Rural Hospital (~55 beds) with ~13505.0 kWh/year
- **Type 4:** District/Referral Hospital (> 145 beds) with ~ 131801.5 kWh/year

In order to identify the location and key characteristics of health facilities in Somaliland, we have used datasets provided by the Government of Somaliland (GoSL) together with the SARA[5] survey dataset. The datasets did provide information about 348 health facilities in the country. GPS coordinates were available for some (but not all) of the facilities. Therefore, the team conducted a geo-tagging exercise to complement the existing data. All health facilities were then assigned a demand target based on their type (see Figure 1 below).

Note! The load of each facility was assigned to the nearest settlement. The total electricity requirement for electrification of those facilities (based on classification and assumption above) was estimated at 1903 MWh/year.

[4] These values are in line with inputs from local counterparts. Please refer to the supporting spreadsheet for a more detailed view of the above.

[5] WHO SARA database

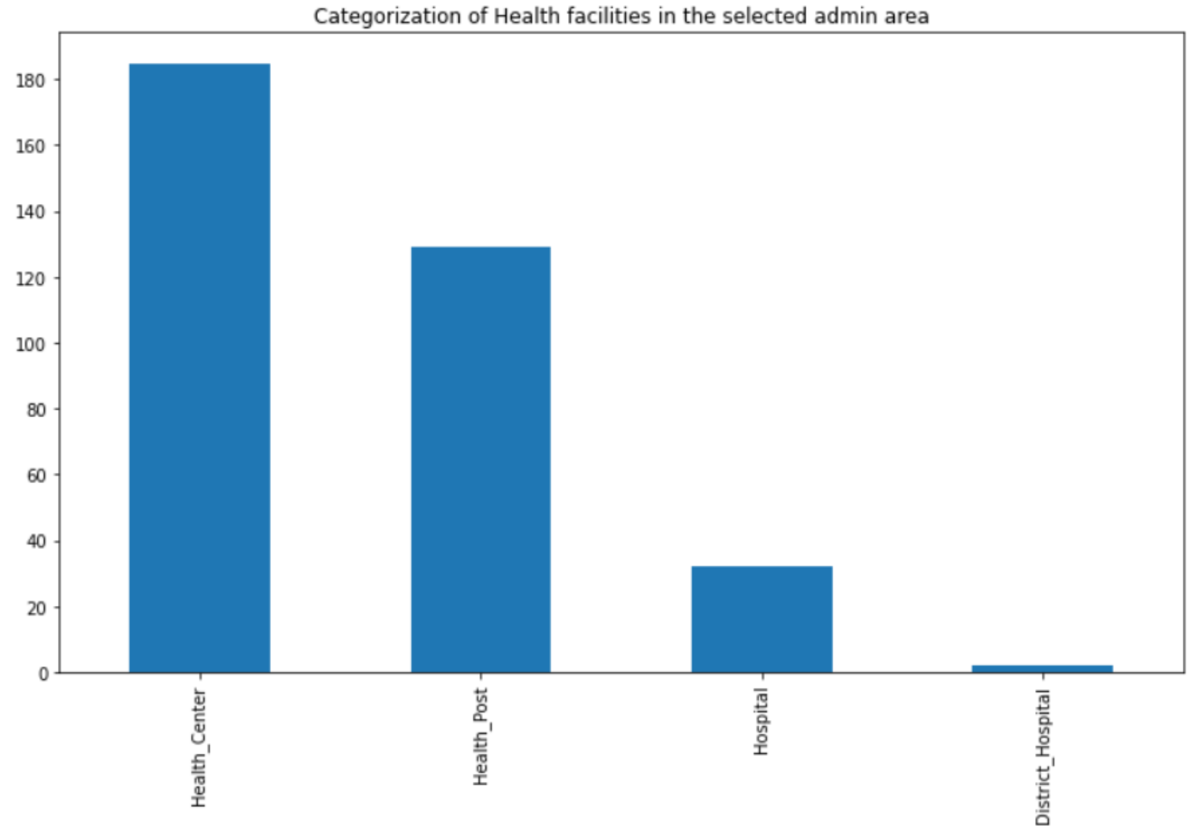

Figure 12. Categorization of 348 health facilities in Somaliland; that is, 129 Health Posts, 185 Health Centres, 32 Hospitals and 2 District Hospitals.

4.4.3 DEMAND FOR EDUCATION FACILITIES

Using data from the GoSL and UNICEF, we have identified the location of 730 education institutions in Somaliland. Their classification by type is presented in Figure 2 below.

Education facilities were classified into 4 main types based on the data range in the above dataset. These are primary schools, secondary schools, higher education and unspecified type. In order to estimate electricity requirements per type we have used the Regional Off-Grid Electrification Project country reports[6] (also used in GEP V.2.0). Thus, power demand was defined for four types of education institutions:

- **Type 1:** Primary schools with ~730 kWh/year
- **Type 2:** Secondary schools with ~2810.5 kWh/year
- **Type 3:** Vocational training & Higher education with ~52925 kWh/year
- **Type 4:** Unspecified type (named as Schools) with ~1642.5 kWh/year

[6] https://documents1.worldbank.org/curated/en/541231554150233127/pdf/Western-Africa-Regional-Off-Grid-Electrification-Project.pdf

Note! The load of each institution was assigned to the nearest settlement. The total electricity requirement for electrification of those facilities (based on classification and assumption above) was estimated at 4383 MWh/year.

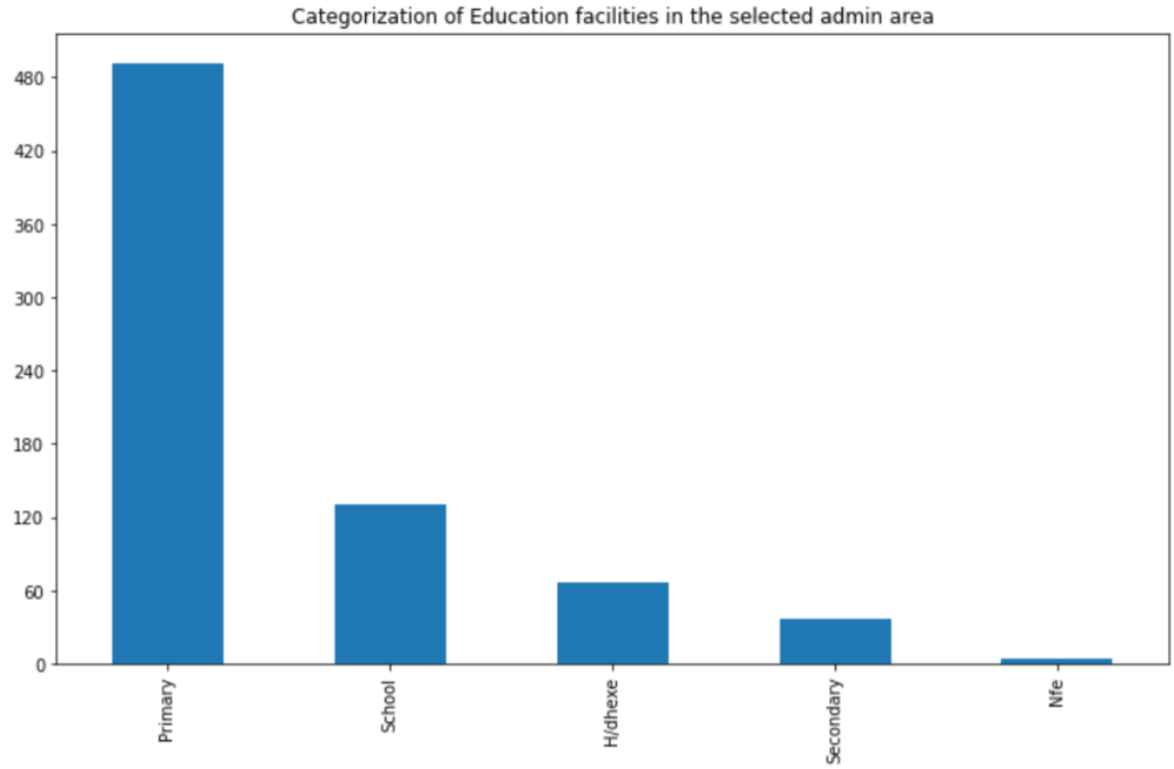

Figure 13. Categorization of 730 geotagged, education facilities in Somaliland; that is, 492 primary schools, 37 secondary schools; 70 vocational schools (66 H/dhexe |4 Nfe) and 131 un-specified schools.

4.4.4 COMMERCIAL & PRODUCTIVE LOADS

Identifying the location of commercial buildings/stores and other productive loads (e.g., irrigation, post-harvesting activities) is a rather challenging task that requires additional resources. In order to account for such loads in the population settlements we have assumed a 25% increase on the typical residential demand targets (described before).

Note! that the total electricity requirement for electrification of commercial and productive loads (based on assumptions above) was estimated at 98.8 GWh/year.

4.4.5 KEY COST PARAMETERS

The costs used in this analysis have originally been retrieved from the GEP and reflect regional average values, including projections for the modelling period 2020-2030. Values in red have been revised based on advice by the Somali counterparts.

Centralized grid:

- **Expected on-grid cost:** 0.07[7] $/kWh
- **Central grid capacity cost:** 2248 $/kW
- **T&D costs:**
    - **HV line (66 kV):** ~365 000 $/km
    - **MV line (11-33 kV):** ~22 000 $/km
    - **LV line (0.2 – 0.4 kV):** ~12 000 $/km
- **HV to MV substation (1000 kVA):** ~25 000 $/unit
- **MV to MV substation (400 kVA):** ~10 000 $/unit
- **Service transformer (50 kVA):** ~5 390 $/unit
- **Distribution losses:** 0.05%
- **Household connection cost/Voltage drop:** 100 $/HH

Off-grid technologies:

- **Expected hybrid (PV-Wind-Diesel) mini-grid cost(s):**
    - PV panel cost: 1 500 $/kWp
    - PV panel life: 25 years
    - Wind Turbine: 2 800 $/kWp
    - Wind turbine life: 20 years
    - Diesel generator: 150 $/kVA
    - Diesel generator life: 10 years
    - Inverter cost: 142 $/kW
    - Inverter life: 10 years
    - Battery cost: 139 $/kWh
    - Diesel cost: 0.5-0.8 $/litre
- **Expected Hydro mini-grid cost(s):**
    - Generation costs: ~3 000 $/kWp
    - Hydropower life: 30 years
- **Expected PV stand-alone (or SHS) costs:**
    - ~9 620 $/kWp if kW < 0.02
    - ~8 780 $/kWp if 0.02< kW < 0.05
    - ~6 380 $/kWp if 0.05< kW < 0.1
    - ~4 470 $/kWp if 0.1< kW < 1

[7] This value was estimated by considering typical electricity export costs from Ethiopia; you may refer to the linked spreadsheet in "Resources" for more details.

- ~6 950 $/kWp if kW > 1

4.4.6 HV BACKBONE COST

For scenarios looking at grid extension we have assumed a standard overnight investment cost of $81.4 million. That is associated to the construction of 223 km HV interconnector with Ethiopia through the Wajaale-Hergeisa-Berbera corridor. The unit cost was assumed at $0.365 million per km based on experience with previous projects in the region (Somali electricity access project).

4.4.7 GRID GENERATION COST

For the grid generation cost (cost of imported electricity) two types of information were considered. First, the team reviewed the power generation cost estimated for Ethiopia that are used in the GEP V.2.0. The values indicate the Average Forward Looking Average cost (FLAC) and Average Marginal Cost (AMC) for the modelling period. FLAC in Ethiopia stands at 0.25 $/kWh and AMC at 0.159 $/kWh; that yields an average value for the transmission and generation tariff at 0.092 $/kWh. In addition, the team had a look at reference PPA agreements for electricity exports in Ethiopia, finding that the bulk export tariff is ~0.07 $/kWh. Since the latter is – probably – a more reflective value of a prospective PPA between Ethiopia and Somaliland, we have decided to use 0.07 $/kWh as the indicative grid generation cost in the analysis.

4.5 MODEL CALIBRATION

In OnSSET, calibration has a twofold meaning. First, it refers to calibrating the urban/rural rate and classification of settlements in regards to the official statistics. Second, it refers to calibrating the classification of settlements as electrified or non-electrified in the base year.

4.5.1 URBAN VS RURAL POPULATION

The characterization of population in Somaliland is slightly complex and follows a four-type classification. There is urban population that lives in major cities and towns; there is rural population that resided in villages; there are nomads that move periodically and there are IDPs. Note that nomads can be further divided to pastoralists (70%) that move more frequently and groups working with agriculture that move less frequently. By combining data from the "*Somaliland Health and Demographic Survey 2020*" and consultations by the Somali counterparts, the team has constructed an indicative table of population characterization per region as indicated below. Note that population values have been calibrated to sum up to 4.2[8] million people. Spatial identification of IDP and nomad population is however nearly impossible with the data at hand. That is, the team has made the assumption that nomads are classified as rural populations. For IDPs it was assumed that 50% will be considered to be living in urban setting and the

[8] It should be highlighted that the total population in Somaliland is not clearly documented. The value of 4.2 million people used in this analysis reflect projection estimated found in the 2020 Somaliland Health & Demographic Survey.

remaining 50% in rural settings. With those assumption in place the total urban population in Somaliland was estimated at 2,271,128 people and the rural population at 1,928,872 people.

Table 1. Estimated population classification in Somaliland in 2020.

	Region	Urban	Rural	Nomads	IDP	Total
1	**Awdal**	332,026	165,820	269,603	9,217	**776,665**
2	**Saaxil**	24,816	19,303	108,056	847	**153,022**
3	**Maroodi Jeex**	926,028	160,247	295,042	51,438	**1,432,754**
4	**Togdheer**	558,016	66,165	178,255	29,716	**832,152**
5	**Sool**	139,576	16,131	216,449	5,560	**377,716**
6	**Sanaag**	184,247	35,535	406,860	1,050	**627,691**
		2,164,707	**463,200**	**1,474,265**	**97,828**	**4,200,000**

4.5.1.1 OPTION A – MATCHING STATISTICS

By using spatial data of roads, settlement, and population distribution in Somaliland, we have tried to match the above values and create a map indicating urban Vs rural settlements. More specifically, we calibrated the settlements using the following rules:

A. Every settlement with >6500 people is considered an urban centre
B. Every settlement that is located <2km from a road is also considered urban

The process resulted in 23 urban centres (with ~1.59 million people) and ~10k smaller settlements (with ~680k people). The following Figure visualizes the result of this process.

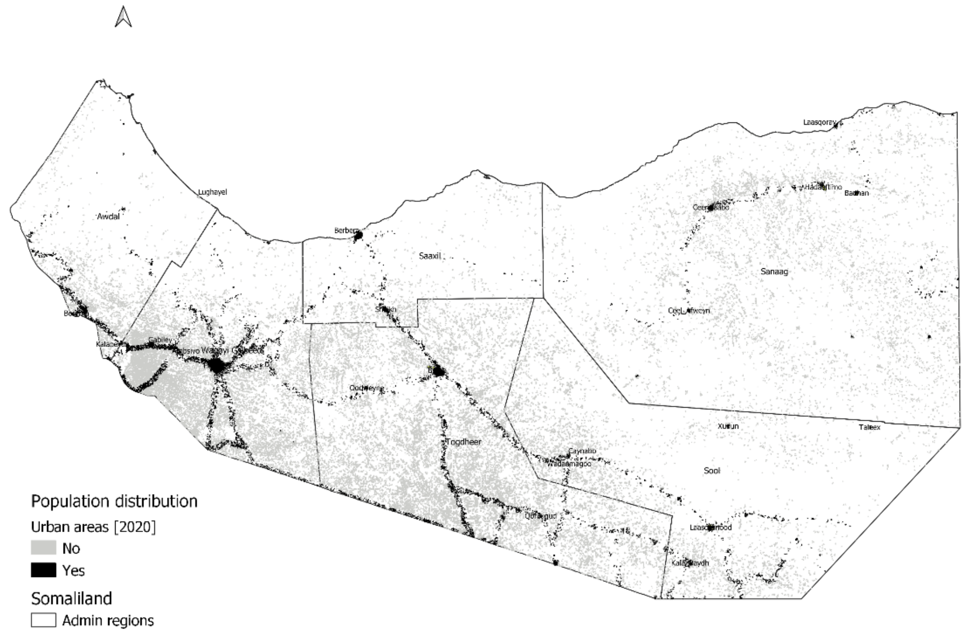

Figure 14. Result of urban/rural population calibration based on rules applied in option A. The total urban population matches with tabular statistics standing at 54.1%.

Although the calibration output matches the statistics (urban rate at 54.1%), one can observe inconsistencies in the results. For example, many small settlements will have to be considered urban in order to match up the statistics (see dark line over the southern border).

Note! that the classification of population between urban/rural is very important for the electrification analysis as residential demand targets are associated with the type of settlement. Urban settlements receive higher electricity targets than rural settlements and that may affect the least cost technology selected as well as the capacity and investment required for electrification.

4.5.1.2 OPTION B – RELYING ON SPATIAL DATA

Therefore, we have applied another approach based on more "sensible rules" consisting of the following:

A. Every settlement with >5000 people is considered an urban centre
B. Every sizable (>100 people) settlement that is located <1.5km from urban centres is also considered urban.

The process resulted in 35 urban centres (with ~1.67 million people) and 140 smaller settlements (with ~70k people). That is, the urban ratio stood at ~41.5%, which is lower than the statistics but with results looking much more reasonable.

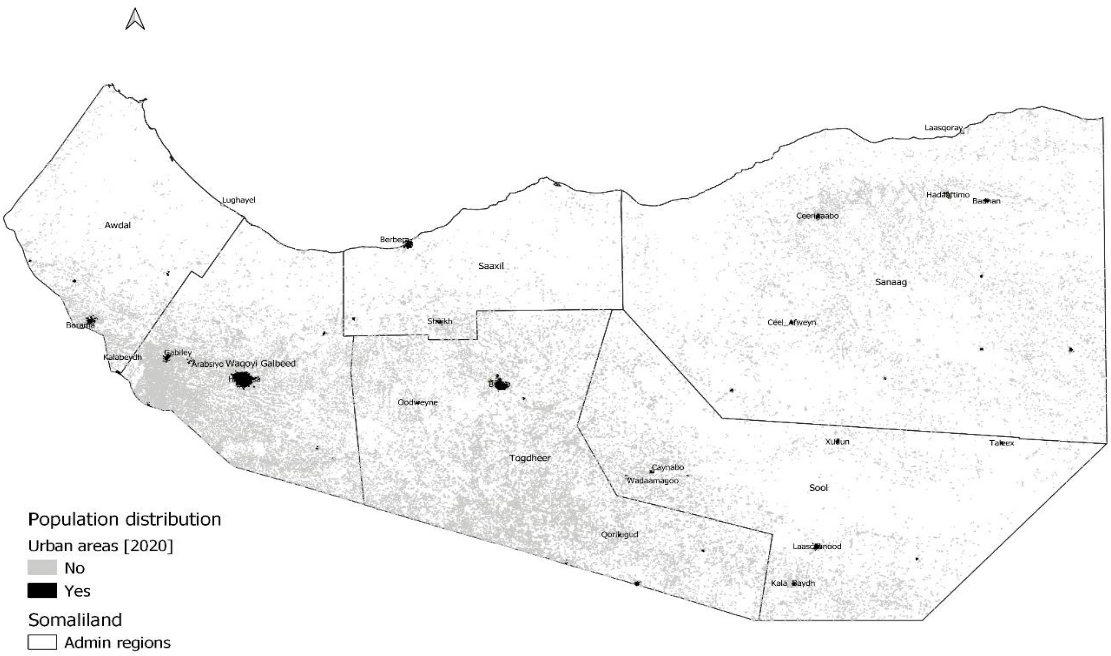

Figure 15. Result of urban/rural population calibration based on rules applied in option B. The total urban population does not match the tabular statistics standing at 54.1% but is more reasonable

In consultation with the Somali counterparts, it was agreed that we proceed with **Option B** in the electrification analysis.

4.5.2 ELECTRIFIED POPULATION IN 2020

An important element of the electrification analysis is the calibration of currently electrified population. That is because served locations are considered the starting point for network expansion whether this refers to existing mini grids (ESPs) or the HV backbone. As per the "Somaliland Health and Demographic Survey 2020" [page 38, table 2.8] the electrification rate in Somaliland is ~44.6% -- 80.7% in urban and 19.3% in rural areas. **Note!** that this comes in contrast to the value presented in the same report on page XXIV (50.3%). Since there is no central grid in Somaliland as of 2020, all served settlements were assumed to be connected to the ESPs. The Figure below shows the list of all 44 ESPs that were considered in this analysis.

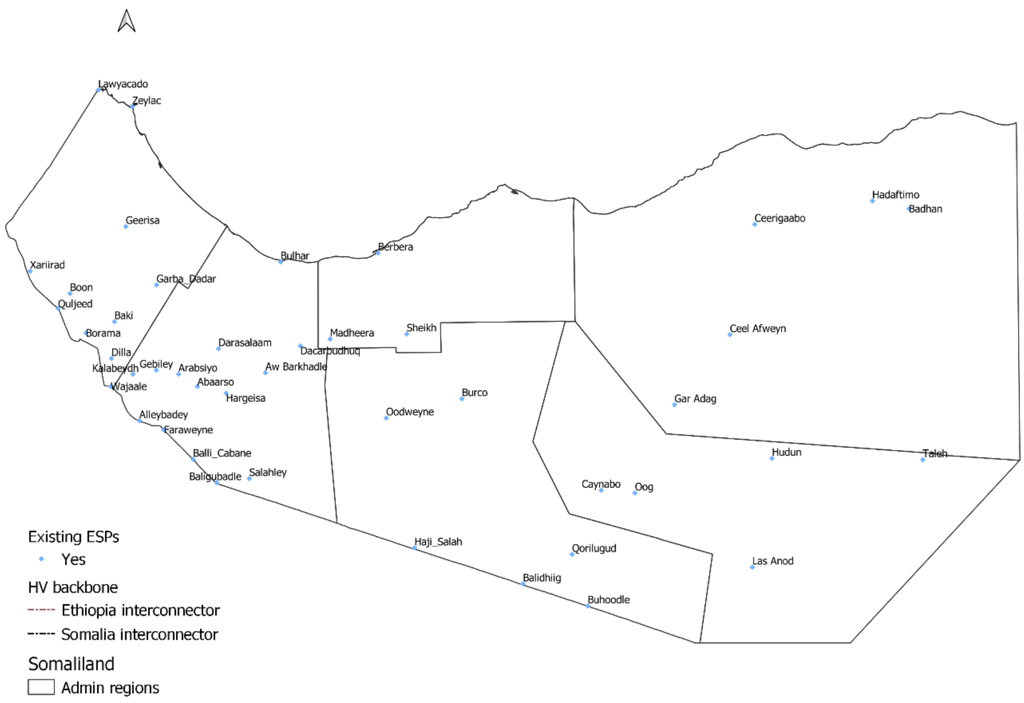

Figure 16. Distribution of the 44 ESPs that were considered active in Somaliland in 2020. The list was based on information and data shared by the GoSL; it was curated by the team based on the latest information available.

Based on the GIS data at hand (location of ESPs) the team tried to match the access rates following several options. Unfortunately, there was no exact match, especially for the rural areas. The most sensible approach was based on the following rules:

A. All settlements that are located <1.5km from an ESP are considered potentially electrified and
B. All potentially electrified settlements have a connectivity rate of 88%

The process resulted the following estimated. The national electrification rate stood at 35%, with the urban electrification rate being 80% and the rural electrification rate ~2% (as shown in Figure below).

It should be noted that the team has tried to understand how the 2020 survey estimated measured access, but unfortunately there was no information available. As one might observe, there is a 17.3% of "connected" population in rural areas that were not able to be identified with the available GIS data. This might be because these populations mainly use electricity for indoor lighting or other minor tasks, powered by sources that are not detectable by nightlights.

In consultation with the Somali counterparts – and in absence of better data/information at the time of modelling – it was agreed that we proceed with the values identified in the electrification analysis.

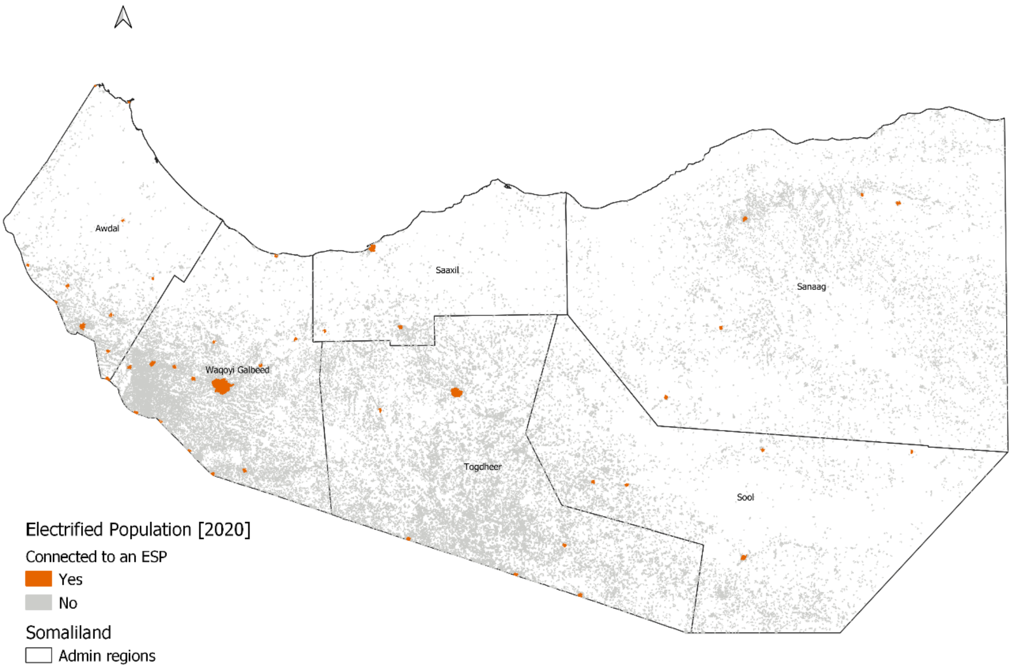

Figure 17. Distribution of electrified settlements in Somaliland (2020) as per OnSSET's calibration. The process yielded an electrification rate at 35% with urban electrification rate at 80% and rural electrification rate at 2%.

4.6 RESULTS AND KEY INSIGHTS

The GEP-OnSSET model for Somaliland generated 96 scenarios (refer to the Appendix for more information). Summary results for all scenarios are available via the SEP. Below we briefly a few findings over those scenarios that – we believe – reflect best the results of the analysis.

4.6.1 THE ROLE OF OFF-GRID SYSTEMS

Currently, most of the existing electricity in the country is generated and distributed by off-grid systems (via ESPs). Off-grid systems were found to play a major role in the electrification rollout in our analysis as well.

The reference scenario indicates that in 2030, ~41.3% of the population in Somaliland finds mini grids as the least cost electrification option. That translates to ~2.32 million people or ~358.2 thousand households. The great majority of them are PV-diesel hybrid systems.

The remaining population finds Solar Home Systems (SHS) as the least cost electrification option in 2030. SHS population share stands at 58.7% in 2030. That is, ~3.3 million people or ~585 thousand households are expected to be served by SHS. Note that ~97% of these people live in rural settlements; the remaining reside in small peri-urban settlements.

The total investment required to achieve full electrification by 2030 in Somaliland – in the reference scenario – was estimated at $344.9 million. This breaks down to ~$99.5 million for deployment of mini grids and ~$245.4 million for SHS. In terms of additional power capacity, the analysis indicates that an additional 141.6 MW is needed for the universal electrification target to be achieved. This breaks down to 90.9 MW of SHS and 50.7 MW of mini grids. The annualized electrification cost is estimated at ~$35 million.

The electrification rollout can be subject to different policy constraints. In this case, the model estimates the investment cost per capita for the least cost technology in each settlement and uses that information in order to prioritize electrification in the two defined timesteps, namely 2020-2025 and 2025-2030. The model foresees that by 2025 the electrification rate in Somaliland will reach ~67.5%. The role of mini grids in this intermediate target is quite important. It is estimate that in 2025, ~59% of population can receive access via mini grids, while the remaining 41% via the deployment of SHS. This roadmap – associated with the reference scenario – is estimated to require an investment of ~$156.3 million ($63.6 million for mini grids and $92.7 million for SHS) between 2020-25. It will also require and additional capacity of 62.3 MW (28 MW of mini grids and 34.3 MW of SHS) in the same period.

Under a slightly different view, the results indicate that between 2020-2025 about 621.5 thousand households (new connections) will be electrified. That is, on top of what is already connected to the base year. The model estimates that ~344.9 thousand new connections will need to happen via mini grid systems; that accounts for ~69 thousand new connected households per year until 2025. SHS are expected to electrify ~276.6 thousand households until 2025. The rest of connections necessary for achieving 100% access are set to take place between 2025-2030.

It should be highlighted that the reference scenario assumes low level of electricity demand target for the residential settlements (see Key input parameters). In case the targets are higher, we also observe a higher share of mini grids in the final results. For example, in the scenario with high electricity demand target, the share of population in 2030 that finds mini grids as the least cost option increases to 48.9%. This however also pushes the total investment requirements higher, reaching $737 million for full electrification, with an estimated additional capacity of 357 MW. Other parameters such as distribution, PV panel and diesel costs affect the results only marginally. The reader is highly encouraged to seek more granular information on sensitivity parameters via the SEP, the open-source interactive platform that has been developed to summarize and visualize the key results and findings of the analysis for all 96 scenarios run for Somaliland.

4.6.2 THE CASE OF "CENTRALIZED GRID"

Some of the scenarios in our analysis, explored the option of grid extension. In those scenarios, the model looked at how a hypothetical HV line transmitting power from Ethiopia to Berbera through

Hergeisa. Assuming all other parameters remain the same as in the reference scenario, the introduction of centralized grid network changes the electrification results as described below.

Grid extension becomes the least cost electrification option for 22.7% of population in 2030; ~18.7% of population still find mini grids as the least cost electrification option. SHS are once again the key technology for reaching 100% access in 2030, by being the least cost option to 58.6% of population. The overall electrification cost in that case is estimated at $431 million – $102.9 million for grid development, $83.1 million for mini grid deployment and $245 million for SHS. Note that these costs include capital investment for the construction of the HV backbone line estimated at $81.4 million. The estimated additional capacity in this scenario is estimated at ~135.7 MW – 4.6 MW of grid power, 40.5 MW of mini grids and 90.6 MW of SHS.

Note that the above estimates assume that distribution costs are aligned with existing local technologies. In case low-cost distribution technologies are adopted (e.g., SWER lines), the total investment requirements are expected to be reduced by ~$15 million assuming all other modelling parameters remain the same.

In case a “forced” grid extension approach is selected and all settlements within 5km from the HV backbone are electrified via grid connection, the total investment is estimated to increase by $19 million in comparison to the least cost approach. That is due to the “forced” electrification of smaller settlements along the HV lines that otherwise would find off-grid systems more economical.

4.6.3 IN A NUTSHELL

Among all scenarios, the investment requirements for full electrification of Somaliland range between $321.7 – $821.6 million. Scenarios that look at lower demand target and low technology costs indicate a cost at the lower end of the range; when demand target and costs increase, the total CAPEX investment is consequently increased. The median value for the investment requirements is ~$369.5 million. Similarly, the estimated capacity requirements to achieve full access follow a similar pattern ranging between 118.9 – 376.5 MW. Looking at the connection costs (electrification cost per household) we may observe a range between $367.5-984.1 among all scenarios, with the median value at $418.7 per connection.

Mini grids can play a significant role in the electrification rollout plan in Somaliland, but their overall contribution is inextricably connected to the residential consumption targets. In scenarios where the residential demand targets are high, mini grids can serve as the least cost electrification option for 30-40% of the population in 2030. This percentage is – of course – also affected by the associated technology costs; in their most favourable scenario mini grids can electrify up to 61% of population in 2030. In scenarios where distribution and diesel costs are relatively high, stand-alone PV systems are highlighted as the least cost electrification option for most settlements in the country

5 CONCLUSION

It is our great pleasure to present this summary report for the project entitled “Preparation of a Spatial Data Infrastructure and Visualisation Tool of Geo-Spatial Electrification Plan” to the Government of Somaliland and our partners. It is our hope that the information contained within this report will help the GoSL to utilise the electric modelling done by ESMAP, available in the SEP, to the fullest extent possible. With the information in the SEP, along with the geospatial layers available in the SDI, the GoSL has many tools available to them for future planning and analysis of electrification options across the Country.

With Kind Regards

Tim Sutton (Director, Kartoza)

APPENDIX A

ADDITIONAL SEP INFORMATION

NAVIGATING THE SEP

The SEP consists of 96 electrification investment scenarios. There are two main types of scenarios split equally (46 per type). The first type of scenarios explores the electrification roadmap assuming that only off-grid systems (mini grids or SHS) are available until 2030. The second type of scenarios assumes that HV backbone is available and thus can be used to connect settlements to what we call the "grid". For each group of scenarios, one might explore a wide range of possible alternatives, designed to capture sensitivity of five key drivers:

- Demand target levels
- Intensification strategy
- Distribution costs
- PV panel costs
- Diesel fuel costs

In the following sections we refer to the above as six *levers*, where the first lever represents the scenario type (only off-grid or both grid & off-grid) and the five other levers represent the five drivers.

LEVER 1. TRANSMISSION NETWORK OUTLOOK

- **Option 1. Electrification mix consisting of solely off-grid technologies**
  If selected, the results include mini grid and SHS technologies only. The technology that can meet the demand at the lowest cost in each location is identified as the least-cost technology.
- **Option 2. Electrification mix consisting of both grid & off-grid technologies**
  If selected, the results include mini grid and SHS technologies, as well as a national HV backbone.

LEVER 2. INTENSIFICATION STRATEGY

- **Option 1. No intensification**
  By default, the OnSSET model chooses the least-cost electrification technology within each settlement. This means that in some cases a mini grid or SHS can be chosen as the least-cost technology, even in areas very close to the existing or planned network. This option considers a purely least-cost approach

where settlements connect to existing MV networks or potential future HV networks only if it is the least-cost option.

- **Option 2. 5 km intensification**

  This option includes a target of connecting all settlements within 5 km of the existing MV networks or the HV backbone network, even if this is not the least-cost option, but only if the connection cost per household is below a certain threshold. In the results presented here the threshold is set to 2000 USD/household.

LEVER 3. DEMAND TARGET

This lever examines three levels of residential electricity demand from low to high. Note that for each case targets are differentiated between urban and rural. There is also a differentiation of demand targets based on the economic status of each settlement. The latter was based on the GDP distribution of the country (see Input datasets).

- **Option 1. Low**

  Urban settlement target:
  - 300 kWh/household/year (for typical settlements)
  - 600 kWh/household/year (for wealthier settlements)

  Rural settlement target:
  - 60 kWh/household/year (for typical settlements)
  - 150 kWh/household/year (for wealthier settlements)
- **Option 2. Medium**

  Urban settlement target:
  - 300 kWh/household/year (for typical settlements)
  - 1000 kWh/household/year (for wealthier settlements)

  Rural settlement target:
  - 60 kWh/household/year (for typical settlements)
  - 300 kWh/household/year (for wealthier settlements)
- **Option 3. High**

  Urban settlement target:
  - 750 kWh/household/year (for typical settlements)
  - 1500 kWh/household/year (for wealthier settlements)

  Rural settlement target:
  - 60 kWh/household/year (for typical settlements)
  - 450 kWh/household/year (for wealthier settlements)

LEVER 4. DISTRIBUTION COSTS

This lever examines the role of MV and LV line costs

- **Option 1. Cost of existing (local) technologies**

  This option is based on current MV and LV costs reported by ESPs in Somaliland.

- **Option 2. Low-cost distribution technologies**

  This option is based on best practices for electrification from selected international sources.

LEVER 5. MINI-GRID PV PANEL COST

This lever examines the role of PV panel costs for mini grids.

- **Option 1. Low**

  The low-cost option is based on international benchmarks/targets for 2020 as reported by ESMAP's *"Mini Grids for Half a Billion People"* publication. The value stands at ~750 $/kW.

- **Option 2. High**

  The high-cost option is based on local costs reported by the Somali counterparts. The value stands at 1500 $/kW.

LEVER 6. DIESEL FUEL COST

Two options for diesel fuel cost were selected in order to test the results' sensitivity on this parameter (especially hybrid mini grids). Both values were suggested by the Somali counterparts.

- **Option 1. Low**

  Value set at 0.5 $/litre.

- **Option 2. High**

  Value set at 0.8 $/litre.