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# ENERGY ACCESS EXPLORER: DATA AND METHODS

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## ABSTRACT

To effectively expand energy access, government planners need to understand and have access to data and analytical tools that capture key attributes of the unserved and under-served populations they are trying to reach. (Today about 840 million people lack access to electricity.) Medium- to long-term energy planning tools used by planners consider spatially aggregated regions to solve complex cost-optimization problems. Although recently developed energy planning tools based on geographic information systems (GIS) focus on identifying technology and investment needs to provide access to unserved areas, these tools currently integrate limited information on demand and affordability. We need a better understanding of the needs and constraints of these new customers if we are to supply electricity in an economically sustainable manner. This paper introduces the methods and data used in Energy Access Explorer. The latter is an online, open-source, interactive platform that analyzes spatial data related to energy supply and demand and a population's unique attributes. Location-specific resource availability and infrastructure data are used to indicate energy supply, and demographic data and data on the social and productive uses of electricity help visualize demand. Together, these supply and demand indicators enable more comprehensive and geographically targeted energy planning not only for energy planning institutions but also for clean energy entrepreneurs and development finance institutions and donors.

## CONTENTS

*Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.*

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# 1. INTRODUCTION

Energy is a critical service that is highly interconnected with socioeconomic development and human well-being (World Bank 2017). A number of studies point out that the level and the quality of health services, education, gender equality, indoor environment, and several daily activities (such as lighting, heating, cooking, telecommunications) can be upgraded with access to modern energy. Yet, 840 million people live without electricity globally (IEA et al. 2019).

Often, due to the lack of funding for data collection and management and the needed enabling environment (incentives and regulations, strong institutions, and strategic planning), policymakers, business leaders, and civil society in developing countries cannot easily access the data they need to effectively expand energy access. For these stakeholders, there is usually no established means or tool that aggregates, analyzes, and disseminates location-specific and energy-related data (Moner-Girona et al. 2018). Scarce and scattered data negatively impact energy planning, making it less accurate.

In fact, the investment estimates for reaching universal access vary greatly. These estimates range from US$12 billion to US$279 billion per year (Bazilian et al. 2014; Pachauri et al. 2013; Johansson et al. 2012). Such estimates usually are based on medium- to long-term cost-optimization planning tools that do not consider characteristics related to the spatial fluctuation of both energy demand and supply. However, these fluctuations are critical when planning for regional energy systems. Customers' actual and potential needs (in terms of their ability to pay and the level of service needed), as well as their social and productive uses of electricity, differ from one location to another, as does the energy resource availability and power infrastructure.

With sustainable energy being a vital pillar for socioeconomic development (McCollum et al. 2018), there is an urgent need to accelerate modern energy services to unserved and under-served areas. The expansion of energy access and the associated investment decisions require proper energy planning and access to reliable data and transparent analytical tools. Open, granular data and bottom-up approaches and proxies for assessing both the demand and the supply side of energy access will enable the design of more viable electrification strategies.

Leveraging the power of global satellite imagery with data from local databases, and considering the multidimensionality (various elements related to demand and supply) of energy access, the World Resources Institute (WRI) collaborated with international partners and experts as well as local stakeholders in developing countries to develop Energy Access Explorer.

Energy Access Explorer is an online, open-source, interactive platform that brings together and analyzes several spatial data sets on both energy supply and demand. This is a multi-criteria analysis tool that uses current, location-specific resource availability and infrastructure data to represent energy supply. It also incorporates demographic data and data on social and productive uses to visualize demand for energy services. Together, these supply and demand indicators enable more comprehensive energy planning.

The use of transparent data and analysis from Energy Access Explorer enables the following:

- **Strategic energy planning.** Analysts and/or decision-makers within energy planning functions (a rural electrification agency, a planning unit of an energy ministry, etc.) can use the tool to improve linking electrification and socioeconomic development to meet people's needs. Energy Access Explorer complements the cost-optimization planning tools these agencies use and provides a bottom-up representation of aspects of affordability and demand. Further, it serves as a database that aggregates up-to-date information. This reduces high transaction costs for data aggregation and sharing.
- **Expansion of energy access markets.** Off-grid and mini-grid developers can use the tool to better assess the level of service needed. Understanding where their customers are likely to be located and where there is a concentration of demand will help clean energy entrepreneurs identify market opportunities.
- **Investment for impact.** Analysts and/or decision-makers within development finance institutions and donors can understand better where to most effectively channel funds into electrification efforts to ensure that no one is left behind.

This technical note is structured as follows: Section 1 briefly introduces the importance of geospatial planning in energy access and sets the objective of Energy Access Explorer. Section 2 describes the methodology behind the development of the tool. Section 3 concludes and suggests areas for further work.

# 2. METHODS

Energy Access Explorer is a modular geospatial tool that allows users to create a custom multi-criteria analysis to identify and prioritize areas in developing countries where energy access can be expanded. The main steps followed in developing Energy Access Explorer are summarized in Figure 1.

## 2.1. Data

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

### 2.1.1. Data Scoping

The first step in the tool's development process was to identify functions that reflect user requirements and data sets that need to be collected and incorporated into the platform. This involved a three-step process:

- Reviewing existing literature on data and methods used for geospatial energy access mapping/planning.
- Administering an energy access mapping survey[1] in order to evaluate the availability, quality, and utilization of geospatial data in energy access mapping. There were 40 stakeholders from 36 different organizations in the private and public sectors, civil society, academia, and development finance institutions who participated in the survey. They provided insights on what users find useful about existing energy access mapping applications and on geospatial analytical and data gaps in their efforts to expand modern energy access to underserved areas.
- Engaging with and sourcing inputs from local stakeholders to ensure that Energy Access Explorer is relevant and applicable to the local context.

Based on the results of the scoping exercise, the following data categories were identified as essential for exploring areas where energy access should be expanded: demographics, social and productive uses, renewable energy resources, and infrastructure (existing and planned).

### Box 2 | Data Scoping in Tanzania: A Stakeholder-Led Approach

We developed the Tanzanian version of Energy Access Explorer in close consultation with key stakeholders to ensure that the tool was relevant to them and captured the data sets and analyses that are critical to the country's planning and policymaking decisions.

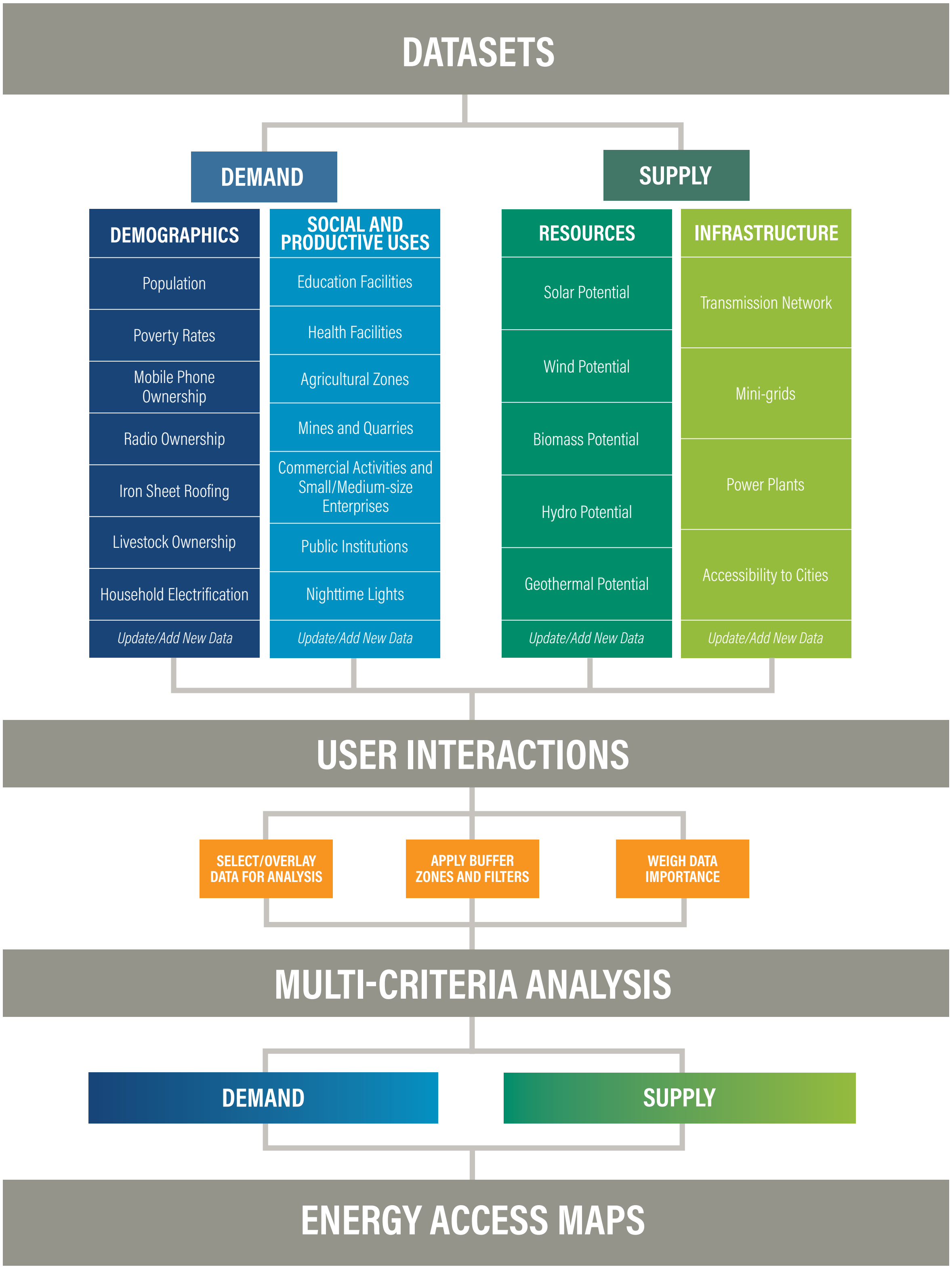
In the very early stages of conceptualizing the tool, we identified key stakeholders, including government planning agencies such as the Rural Energy Agency and the Ministry of Energy, clean energy developers, development finance institutions, and civil society organizations that could be potential users of the tool. In addition to the energy access mapping survey, we convened the stakeholders to share the vision for the tool and to source their inputs on what data sets and analytics would be valuable to them as they plan for and implement energy access initiatives. These inputs informed the development of the beta version of the tool. The stakeholders were then reconvened around the beta version to share feedback of the tool's user experience (for example, the ease of navigating the tool, conducting analyses, and so forth). We continue to engage these stakeholders as we further refine the tool in order to ensure that key planning and policy needs are captured in its architecture.

#### DEMOGRAPHICS

The demographic data incorporated in the platform include the following:

- **Population density** data are critical for understanding the distribution of people across a country and are useful for planning for future energy infrastructure (Tiecke 2016). Combined with energy use per capita, population density data significantly influence energy demand estimations.
- **Energy expenditure** is a critical parameter in energy planning. For the private sector, (nonelectricity) energy expenditure estimations are used to estimate a consumer's willingness to pay for electricity services. Willingness to pay relates to profitability, which drives the private sector. Furthermore, high energy expenditure for the poor results in energy poverty and exacerbates absolute poverty. Thus, energy expenditure estimations are important also to the public sector and development organizations that, among others, aim to increase

Figure 1 | **Methodological Framework of Energy Access Explorer**



*Source:* WRI.

energy access for the last mile. However, since granular data on energy expenditures are usually scarce, relevant proxies are used to understand aspects of affordability. These may include **iron sheet roofing**, **radio ownership**, **mobile phone ownership and coverage,** and **livestock ownership.** The proxies provide insights about a household's ability to pay for electricity (Klasen and Mbegalo 2016). In certain geographies, for example, iron sheet roofing may reflect an individual's interest in owning modern goods (Klasen and Mbegalo 2016). Radio and mobile phone ownership also drive the demand for electricity because of the need to recharge them (Ondraczek 2013). Further, mobile coverage rates may indicate potential to adopt pay-as-you-go service delivery models to increase electricity access in unserved areas. Furthermore, **poverty rates** can be used as a proxy for whether the population can afford a certain supply of electricity (Fankhauser and Tepic 2007).

- **Household electrification rate** data map the percentage of the population (relative to the total population) that have electricity in their households or the lack thereof to reflect unmet demand.

### SOCIAL AND PRODUCTIVE USES

Social and productive uses of electricity constitute significant factors that influence electricity demand and boost income and welfare. These activities are typically in the sector of agriculture, rural enterprise, health, and education (GIZ et al. 2013):

- **Education** and **health care facilities** are potential sites for expanding access to electricity. This provision may improve the quality of education and health care services (Cabraal et al. 2005).
- **Agriculture** is a large consumer of energy, and agricultural areas (data integrated in the platform) can be used to identify areas where electricity could be useful for irrigation, fertilization, or other efficiency measures (FAO 1995; Stanhill 2012).
- **Mines and quarries** are other important consumers of energy, and mines in rural areas may be suitable for off-grid power solutions (Devasahayam et al. 2016).
- **Nighttime lights** illustrate existing demand for electricity and are an indicator of socioeconomic activity. (Bertheau et al. 2017; Bruederle and Hodler 2018).

### RENEWABLE ENERGY RESOURCES

Local renewable energy resources can play an important role in expanding energy access in a viable, clean manner in unserved and under-served areas. Planners as well as off-grid and mini-grid developers have a strong interest in geospatial renewable energy potential data sets that facilitate decision-making regarding the deployment of clean energy solutions. Energy Access Explorer incorporates data on global horizontal irradiance (indicating solar power potential) (Kariuki and Sato 2018), wind speed (indicating wind power potential) (D'Amico et al. 2015), small-scale hydropower potential (mini and small hydropower potential) (Kaunda et al. 2012), and geothermal energy potential.

### INFRASTRUCTURE

Proximity to power and road infrastructure is essential in planning for the expansion of energy access. It influences the selection of the optimal supply type and the associated investment needs for future energy projects:

- **The existing and planned transmission and distribution network** provides the locations of infrastructure and, combined with nighttime lights, can indicate which part of a country is or may become connected. The transmission and distribution network is also one of the critical data sets for understanding which unserved areas should be supplied via a grid extension or a configuration of off-grid technologies (Bertheau et al. 2017; Mentis et al. 2017).
- **Powerplant locations** show where power is being generated and illustrate grid existence and potential grid extension (Mentis et al. 2017).
- **Locations of existing mini-grids** display current supplies of electricity off the main grid and potential future economic developments (Eder et al. 2015). Also, mini-grid locations may indicate areas where projects have been successfully implemented (Odarno et al. 2017).
- **The road network and accessibility to cities** gives an insight about how well connected a specific area is. Travel time to cities can be used as a proxy for accessibility to fuel, education, health services, finance services, and jobs (Weiss et al. 2018).

It is noteworthy that the data sets (and proxies) may differ from one geography to another and that this list is not exhaustive. This emphasizes the importance of the scoping exercise to ensure the tool reflects the needs of the local users.

### 2.1.2. Data Collection

Energy Access Explorer incorporates data from global, national, subnational, census, remote sensing, and crowdsourcing databases and platforms that are either publicly available or are provided by international partners or local stakeholders. To ensure relevant, timely, high-quality information for the users, data should meet certain criteria, including the following:

- *Credibility of the source*. Data should have gone through a peer review process and/or include comprehensive citations and must be supported with a description of the methods used for data generation/collection.
- *Metadata*. The original source has a detailed methodology that is clearly written and legitimate.
- *Accuracy*. Data are free of errors and complete.
- *Accessibility*. Data are in a usable format, such as a table, shapefile, GeoJSON, or GeoTIFF.
- *Spatial coverage*. Data are complete for the studied geography.
- *Spatial resolution*. Data are of the highest spatial resolution available for the data type.
- *Timeliness*. Data are recent enough to be of use to a decision-making process and, ideally, have been updated within the past five years.[2]
- *Public license*[3] Data are public, can be shared, and are available for download according to a license such as Creative Commons (3.0 or 4.0) or Open License, or they are in the public domain.

### 2.1.3. Data Processing

Energy Access Explorer features a number of geospatial data from different sources and in various formats. To enable integration, spatial analysis, and visualization in the platform, data need to be harmonized. Spatial data need to go through a systematic transformation (otherwise known as a projection) whereby the locations of data are projected from a sphere to a plane map. All transformations will include some distortion, but they preserve certain aspects of the world, such as shape, distances, or direction. For Energy Access Explorer, the widely used WGS84 Web Mercator Projection (EPSG:3857) was selected to allow for integration with other relevant online spatial platforms via web mapping services (ESRI 2010).

Energy Access Explorer processes vector (points, lines, and polygons) and raster data (grid-cell data and pixelated images). Point and line vectors are converted into distance raster layers in which each pixel has a distance value to the nearest point or line. This allows the analysis to consider proximity to the nearest feature (see Table 1). For example, proximity to grid infrastructure is an essential indicator of whether a grid extension would be able to expand access to electricity or whether an off-grid solution would be preferred. Furthermore, data are clipped to the geography boundaries accepted by the respective governments.[4]

It should be noted that some of the administration-level data sets (such as mobile phone and livestock ownership) are used as filters on the tool so that users can eliminate parts of the map that fall outside of their set range. This function allows the user to account for the low-resolution data but not make the mistake of assuming one value applies to many square kilometers equally. Once these data become available in higher resolution in the future, they can be incorporated into the calculation. This is because Energy Access Explorer has been developed in a modular way with the goal of easy integration of new data.

All data are stored in cloud storage and are integrated into the site to allow for cloud-based geospatial analysis.[5]

## 2.2. Complexity of the Tool and User Interactions

As shown in Figure 1, Energy Access Explorer aggregates data sets related to demand and supply. When users pick a country to work in, they are prompted to select what they want to do with the tool: explore new markets for clean energy technologies, plan for electrification, or invest for impact. After picking a country, the platform loads the selected map and displays preselected data sets. These default data sets are based on the survey responses and experts' judgment, but they can be modified. Users have the option to select among the available data sets and overlay them on the map. They also have the ability to change the range of each data set, the buffer around point and line data sets (e.g., health centers and grid network), and the importance of each data set by changing its weight in the calculation. Data sets that have a lower resolution (available in tabular format) are used to provide context and can be turned on to use as filters.

The platform synthesizes this data and uses a multi-criteria analysis that produces four "heat maps" to guide the users to areas with potential for growth in energy access markets. These heat maps show the Energy Access Potential, Demand Index, Supply Index, and Need for Assistance Index (see Section 2.3). The user can switch between viewing the underlying data sets and the results of the multi-criteria analysis. The analysis results can be downloaded as a geographic information system (GIS) raster file to be used offline for further analysis. Furthermore, data and maps as well as summary tables and graphs can be downloaded as a pdf report. The data platform complies with WRI's open data commitment of making our data and the results of our research freely available for all to use.[6] Energy Access Explorer is an open-source platform, and all of the code is available on GitHub[7] for others to use and build upon.

## 2.3. Multi-criteria Analysis

The main function of Energy Access Explorer is a multi-criteria analysis (MCA) to identify areas of interest to expand energy access. MCA methods are a branch of operations research models  that are suitable for addressing complex problems featuring different perspectives and various data (Cristobal 2012). Increasingly, these have been utilized in decision-making for sustainable energy because of the multidimensionality of energy planning and the complexity of socioeconomic systems (Wang et al. 2009; Kumar et al. 2017).

The MCA produces four indices: Energy Access Potential, Demand Index, Supply Index, and Need for Assistance Index. Below, we cover each in turn. To develop these indices, we first placed all indicators on a comparable scale. Both a simple linear and a logarithmic transformation are available in the platform.  All data sets are normalized to a scale of zero to one according to predefined thresholds. Thresholds can be determined using different methods (correlation analysis, literature review, and expert judgment) and can be customized in the content management system of the platform by the platform administrators. Distance rasters are inverted to create proximity rasters where values of one indicate the location of the point or line, and zero indicates areas that are far from the point or line.  The processed data sets go into a calculation to create the MCA. The results of the analyses are also normalized to a scale of zero to one to make the values meaningful (see Table 1).

All indices are calculated for each square kilometer of the select geography. This allows each square kilometer to have a distinct value, providing a detailed map of the area of interest.

### Box 3 | The Web Architecture of Energy Access Explorer

The web architecture of Energy Access Explorer is developed based on a "simplicity and standards first" approach.

A stand-alone web server (PostgREST) turns a database (PostgreSQL) directly into an application programming interface (RESTful API). REST, or representational state transfer, is used to build an API that allows users to connect and interact with cloud services. When the RESTful API is called, the server will transfer a representation of the state of the requested resource to the user. For example, when the user selects a data set in the platform (e.g., solar irradiance) and applies certain filters (e.g., solar irradiance higher than 2000 kilowatt-hours per square meter), the API will return this exact map.

PostgREST also provides authentication mechanisms via standard methods (JSON Web Token). Given this advantage, data validation (e.g., data type checks, allowed character checks) and permissions (e.g., keeping unauthenticated users from editing the database or keeping private content that is not ready to be published) are delegated to the PostgreSQL database. The database is set in native SQL and PostgREST handles the API and the hypertext transfer protocol (http) server.

Then, an NGINX instance is set as a proxy to handle domain resolution, caching directives for static assets (such as images, libraries, and other content that does not require processing). Optionally, since it could be hosted on a different server, the NGINX instance could serve the rest of the infrastructure.

A content management system (CMS) is developed to allow administrators to easily integrate data and metadata. Data from other APIs can also be integrated in the platform. Both the CMS and the multi-criteria analysis tool (explained in Section 2.3) are written in plain JavaScript (ES6) and fetch the data from the API.

*Note:* More information about the web architecture is available on the GitHub repository: https://github.com/energyaccessexplorer.

**Demand Index.** The Demand Index is the weighted sum of normalized demographic data and social and productive use data. The formula inverts the percentage of people who live below the poverty line to provide the number of people who live above the poverty line, which is used as a proxy for where people have an ability to pay for electricity. Proximity to social and productive uses, such as schools, hospitals, and mines, are added so that higher values highlight areas closer to potential demand. Nighttime lights are added to identify where there is already light and existing demand for electricity. The product of this index has high values where people have an ability to pay, are close to productive uses, and have a current demand for electricity, which creates a map of existing and potential demand.

For each area $j$, the weighted sum Demand Index is calculated as

EQUATION 1

$$Demand\ Index\ (DI)_j = \frac{\sum_{i=1}^{D} w_i * NDD_i}{\sum_{i=1}^{D} w_i}$$

where $w_i$ (i=1,2…D) is a weighing factor for the ith Normalized Demand Data (NDD) set (referring to the normalized values of data under the demand group, such as population density, poverty rates, etc.).

The final displayed Normalized Demand Index (NDI) is computed as

EQUATION 2

$$NDI_j = \frac{DI_j - \min(DI)}{\max(DI) - \min(DI)}$$

**Supply Index.** The Supply Index is the weighted sum of normalized renewable energy resources potential and existing infrastructure. Solar and wind potential values are added together, and proximity to potential hydropower and geothermal sites are added to find areas with high renewable potential. Proximity to existing and planned transmission lines, mini-grids, power plants, and cities are added to identify where there is potential for renewable energy and there is existing or planned infrastructure to make a map of existing and potential supply.

EQUATION 3

$$Supply\ Index\ (SI)_j = \frac{\sum_{i=1}^{S} w_i * NSD_i}{\sum_{i=1}^{D} w_i}$$

where $w_i$ (i=1,2…S) is a weighing factor for the ith Normalized Supply Data (NSD) set (referring to the normalized values of data under the supply group, such as global horizontal irradiance, distance to the grid network, etc.).

The final displayed Normalized Supply Index (NSI) is computed as

EQUATION 4

$$NSI_j = \frac{SI_j - \min(SI)}{\max(SI) - \min(SI)}$$

**Energy Access Potential.** The Energy Access Potential Index is the weighted sum of the Demand Index and Supply Index. It indicates areas where the population has an ability to pay for electricity and that are close to social and productive uses of energy, have potential for renewable energy, and have existing or planned infrastructure. Thus, the Energy Access Potential displays a score for how much current and potential demand and current and potential supply for electricity there is in the areas of interest (see Figure 2).

EQUATION 5

$$Energy\ Access\ Potential\ (EAP)_j = \frac{w_d * NDI_j + w_s * NSI_j}{w_d + w_s}$$

where $w_d$ is the weighing factor for the NDI and $w_s$ is the weighing factor for the NSI.

The final displayed EAP is computed as

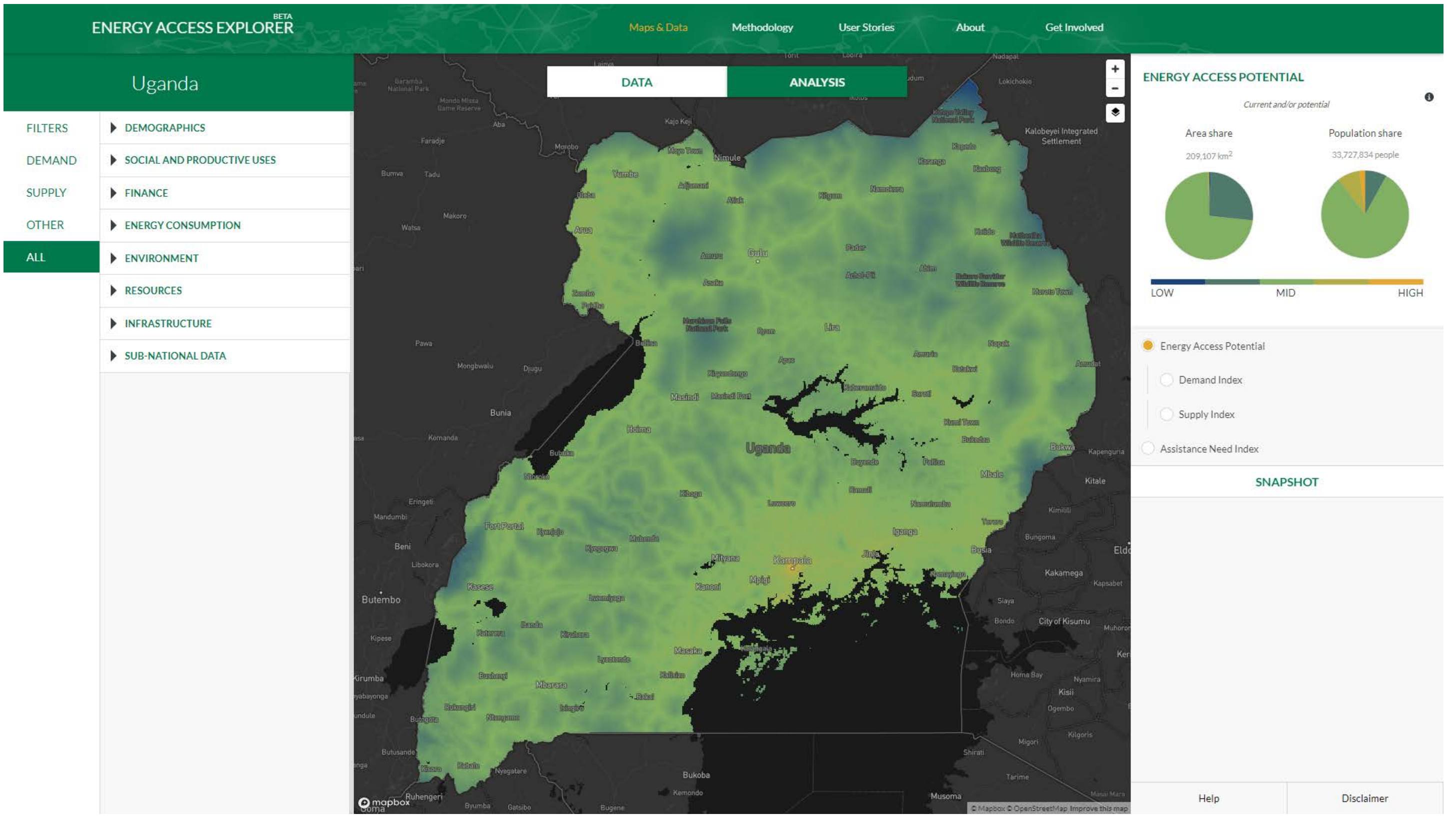
EQUATION 6

$$EAP_j = \frac{EAP_j - min\ (EAP)}{max\ (EAP) - min\ (EAP)}$$

**Need for Assistance Index.** The Need for Assistance Index is a weighted sum of certain demand and supply data and is used to indicate areas where financial assistance may be needed more (see Table 1). For example, areas with the potential to develop economic activity (e.g., agribusinesses) and significant social loads—but with current low ability to pay—may require more financial support than areas where economic activities are already high, all else being equal. Assistance to finance renewable energy for agriculture would need to be integrated into a full package from the agriculture sector or organizations supporting the sector.

## Figure 2 | Snapshots of Energy Access Explorer for Uganda

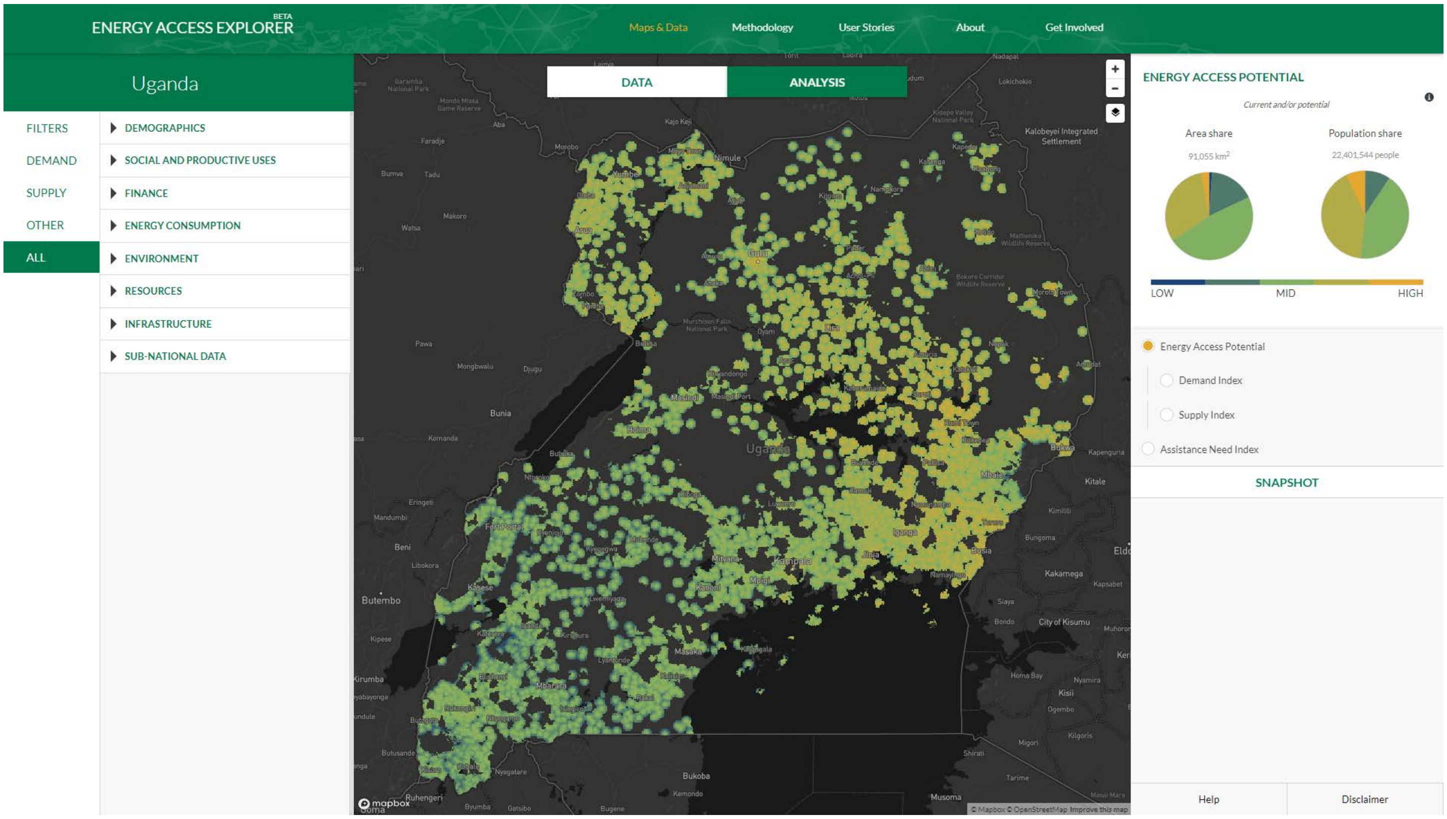
*Here, the Energy Access Potential is visualized for Uganda. This can be used to identify "low hanging fruit" areas where energy access may be expanded.*



*Source:* Energy Access Explorer (beta version), https://www.energyaccessexplorer.org.

## Figure 2 | Snapshots of Energy Access Explorer for Uganda (cont.)

*This shows areas with low access rates, high current and potential social loads (education and health facilities), and high solar irradiance.*



*Source:* Energy Access Explorer (beta version), https://www.energyaccessexplorer.org.

## Table 1 | Data Categories and Energy Access Potential, Demand, Supply, and Need for Assistance Indices

| | DATA SET | UNIT | ENERGY ACCESS POTENTIAL | DEMAND INDEX | SUPPLY INDEX | NEED FOR ASSISTANCE INDEX |
|---|---|---|---|---|---|---|
| | | | VALUES THAT PRODUCE A HIGH INDEX SCORE | | | |
| DEMAND | **Demographics** | | | | | |
| | Population | People/km$^2$ | High density | High density | | High density |
| | Poverty | % of population < US$2/day | Low rates of poverty | Low rates of poverty | | High rates of poverty |
| | **Social and Productive Uses** | | | | | |
| | Education facilities | km to nearest education facility | Low (close) | Low (close) | | Low (close) |
| | Health care facilities | km to nearest health care facility | Low (close) | Low (close) | | Low (close) |
| | Irrigated croplands | Metric tons of production | High rates of production | High rates of production | | High rates of production |
| | Rain-fed croplands | Metric tons of production | High rates of production | High rates of production | | High rates of production |
| | Mines and quarries | km to nearest mine or quarry | Low (close) | Low (close) | | Low (close) |
| | Nighttime lights | Calibrated radiance (0–255) | High radiance values | High radiance values | | High radiance values |
| SUPPLY | **Resources** | | | | | |
| | Solar potential (yearly sum of global horizontal irradiance) | kWh/m$^2$ | High solar potential | | High solar potential | Optional |
| | Wind potential (wind speed) | m/s at 50 m | High wind potential | | High wind potential | Optional |
| | Locations of geothermal potential | km to nearest potential geothermal site | Low (close) | | Low (close) | Optional |
| | Locations of mini and small hydropower potential | km to nearest potential hydropower site | Low (close) | | Low (close) | Optional |
| | **Infrastructure** | | | | | |
| | Existing transmission and distribution network | km to nearest transmission line | Low (close) | | Low (close) | High (far) |
| | Planned transmission and distribution network | km to nearest planned transmission line | Low (close) | | Low (close) | High (far) |
| | Mini-grids | km to nearest mini-grid | Low (close) | | Low (close) | High (far) |
| | Power plants | km to nearest power plant | Low (close) | | Low (close) | High (far) |
| | Accessibility to cities | time to nearest city (minutes) | Low (close) | | Low (close) | High (far) |

*Source:* Data sources and all metadata are included in the online platform.

## 3. CONCLUSION

Modern energy access and associated infrastructure planning cannot be addressed without regard for the spatial nature and dynamics of human settlements and economic production.

With the increasing importance of GIS in energy planning and improved computational capabilities, geospatial data can be used to support the expansion of energy access. Energy Access Explorer provides an open, online infrastructure that analyzes spatial demand and supply data to identify areas where energy access should be expanded. There is no one-size-fits-all approach with respect to energy systems. Considering that physical, economic, and social conditions vary from one place to another, we need an in-depth knowledge of local characteristics. As such, the platform enables user engagement by supporting local stakeholders in providing relevant, high-quality data, allowing users to develop their own analyses.

Currently, a beta version of the platform has been developed for Tanzania, Uganda, and Kenya to leverage WRI's engagements in these geographies. Nonetheless, Energy Access Explorer is country agnostic, and the platform can be tailored to accommodate country-specific data needs and GIS functions and can be expanded to include other geographies. Moreover, Energy Access Explorer complements geospatial cost-optimization energy planning tools (e.g., OnSSET, Network Planner, Reference Electrification Model) that focus more on optimizing the supply side (Moner-Girona et al. 2018). Further, it serves as a database that synthesizes up-to-date geospatial information.

Although Energy Access Explorer attempts to aggregate most geospatial data on demand and supply, there is room for continuous improvement of the platform and the available analyses. Energy Access Explorer will be enhanced as more granular or new data and analyses become available. Specifically, outputs of geospatial assessments to estimate demand for electricity to power livelihoods as well as social and economic activities will be incorporated in the platform. Furthermore, outputs of least-cost electrification analyses (such as the levelized cost of electricity and cost-optimal access types) will be included as additional indicators that users can select to identify areas of interest. Finance data, such as location of microfinance institutions and banks, will be added to provide insights on market assistance needs. Research is under way to incorporate the above-mentioned features. Energy Access Explorer offers a transparent approach to bridge science, technology, and policy to provide useful insights in the energy access field at different geographic levels.

## ENDNOTES

1. See the WRI Energy Access Mapping Survey, 2018, available at https://docs.google.com/forms/d/e/1FAIpQLSdbMf0VJ92BnJmKNbZSp4Kj1HWRs9m03oCe5qvmvscrZ109RA/viewform.
2. Censuses usually are carried out every 10 years. Other data sources, such as demographic and health surveys and local databases, should be considered when available to ensure up-to-date data are used to inform decision-making.
3. Key institutional users will be able to use an offline and/or password-protected version of Energy Access Explorer in case they want to use and analyze sensitive data.
4. The clipped raster layers are lowered to a 16-bit unsigned integer file type to make the online analyses faster.
5. Amazon Simple Storage Service (Amazon S3) is used to store the data.
6. For more information about WRI's open data commitment, see https://www.wri.org/about/open-data-commitment.
7. For more information, see GitHub at https://github.com/energyaccessexplorer.

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