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PRACTICE NOTE

Application of GIS in sub-national energy planning in Kenya

Integrating primary data into a least-cost electrification model using OnSSET (case study of Narok County, Kenya)

Practice notes provide rapid analysis of experiences related to a particular project. The analysis and recommendations are limited to the specific context presented in the note and should not be construed to apply more broadly.

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HIGHLIGHTS

- Effective energy plans require access to complete, timely, accurate, reliable, and quality geospatial energy data, but these data are not always available in Kenya.
- This publication describes the process of geographic information system (GIS) data collection, storage, and analysis to support the energy plan for Narok County, a county where, as of 2018, 80 percent of households did not have access to electricity.
- The spatial dimension is important for energy planning as several data related to energy demand, such as demographics and social and productive uses of energy and supply (e.g., grid infrastructure and renewable energy sources), vary from one geography to another and can be used to model the cost of different energy options to meet this demand.
- More investment and capacity building are needed in the collection and aggregation of energy demand and supply datasets into Energy Access Explorer, a GIS data platform, to improve ease of access and analysis to inform energy plans.

Executive summary

Background

Integrated energy planning is essential to achieving United Nations Sustainable Development Goal 7 regarding access to affordable, reliable, sustainable, and modern energy for all. In Kenya, the Energy Act of 2019 requires that all 47 counties develop a County Energy Plan (CEP) to inform the design of the Integrated National Energy Plan (INEP) which will serve as a roadmap to achieve universal electrification (GoK 2019, 23). However, only 16 of the county governments have developed their CEPs (Kipkemoi 2024). The slow progress has been caused by limited technical expertise and insufficient access to data and analytical tools.

To help county governments develop their CEPs, we, a project team from World Resources Institute, Strathmore University, and the Narok County government, worked to create a CEP for Narok County and establish a model that other county governments can follow. The project team was selected based on their complementary skills to draft specific sections of the CEP, along with the overall guidance and support of the county. This publication reviews the steps we took to develop a CEP for Narok County. It provides specific emphasis on the collection and application of geospatial data to provide location-specific insights on demand for and supply of energy, which we then used to propose viable and least-cost energy technology solutions to meet energy demand and achieve universal electrification for each settlement by 2026, while factoring in an affordability analysis of the proposed solutions. These served as critical inputs for formulating the CEP and can be applied in similar energy planning efforts.

About this practice note

Integrated and inclusive energy planning is critical to ensuring that suitable energy solutions at any given location are considered. This then requires extensive collaboration among national and subnational governments and the private sector. To design effective electrification and clean cooking solutions, it is necessary to gain a better understanding of the unique contexts of the end users, including households, businesses, institutions, and small and medium-sized enterprises, among others, due to their varying demographics, socio-economic situations, energy resource availability, and proximity to power infrastructure. Local government agencies and utilities need accurate and up-to-date geospatial data to visualise and analyse end users' energy needs and design appropriate energy solutions that are locally relevant. In most cases, however, geospatial data suitable for energy planning are either scarce, fragmented, inconsistent, tagged as confidential, or exist only at the national level, thus hampering their use for integrated energy planning at subnational levels (Otieno et al. 2022). This publication explains how we addressed some of these geospatial data challenges while developing the energy plan for Narok County.

Methodology

GIS data and analysis are integral to energy planning. We used a GIS toolkit comprising various novel open-source tools, including KoboCollect to collect granular data, Energy Access Explorer to identify high-priority areas for energy access interventions, and Open Source Spatial Electrification Tool (OnSSET) to estimate the technology and investment outlooks for achieving electrification targets. We prioritised using open-source tools as they make updating, replicating, and scaling the approach in other counties easier and require minimal resources. See Table ES-1 for more on these tools.

Table ES-1 | **Main open-source tools used and analysis outputs in the CEP development**

TOOL/ANALYSIS	APPLICATION IN CEP DEVELOPMENT
KoboCollect	Collection of primary data
Energy Access Explorer (EAE)[a]	World Resources Institute developed the EAE tool for various geographies in sub-Saharan Africa, Nepal, and India.[b] The EAE is an open-source, dynamic geospatial information system that enables stakeholders to visualise and analyse high-priority areas where access to energy should be expanded for equitable development. In addition to several geospatial data on energy demand and supply, EAE integrates outputs of least-cost electrification modelling based on OnSSET. This publication describes how we developed the sub-national-level version of the EAE for Narok County as a subset of the national version for Kenya with relevant county-specific data. It also explains how this version can be used for energy planning, thus improving the granularity of the EAE; i.e., using the EAE at the sub-national and local levels.
Open Source Spatial Electrification Tool (OnSSET)[c]	OnSSET is a GIS-based least-cost tool with outputs including least-cost technology choices, energy capacity required, and implementation costs for these technologies to achieve universal electrification for all households by 2026 in Narok County. This publication illustrates how we used OnSSET at the sub-national level to model technological and cost optimisation pathways for achieving universal electrification. This will add to the body of work in this area since most least-cost electrification modelling has been previously done at a national level.
Affordability analysis	We incorporated primary data (gathered using KoboCollect) to the least-cost electrification modelling exercise to model household-level affordability of the technology choices for the sub-counties in Narok if implemented. This analysis can help inform the planning process by highlighting the gap between what households currently pay for electricity and what the proposed solutions would cost them. It also adds a new dynamic to least-cost electrification modelling using OnSSET, which mostly relies on secondary data sources.
Geospatial analysis for institutional electrification	We considered solutions for the electrification of institutions like schools and hospitals through grid densification. We undertook proximity analysis to establish institutions that were 600 metres or more from the distribution transformers. We assumed these institutions were unelectrified as there is a 600-metre transformer radius limitation for electricity connections from the grid in Kenya.[d] We further extracted the unelectrified institutions and overlaid them with outputs from the selected OnSSET modelling scenario. Finally, using GIS proximity analysis, we assigned the institutions a least-cost electrification technology option based on the solution assigned to the nearest settlement cluster.

Notes: a Mentis et al. 2019. b Data.org n.d. c Mentis et al. 2017. d REREC n.d. CEP = County Energy Plan; GIS = geographic information system.
Source: Authors.

Results and expected outcomes

We hope the target audience will use this publication to plan for universal access to clean energy for Narok County to meet current and future demand as well as to demonstrate to similar contexts how open source tools can be used to support energy access.. This publication outlines how GIS tools can be used to map energy demand and supply, how to carry out an analysis that links the two, how primary data collection can be used to derive further insights in least-cost electrification modelling, and how we applied these new datasets and analysis results to Narok's final County Energy Plan. It also addresses one of the biggest barriers to developing CEPs: scarcity of data and insufficient technical capacity (MoEP 2018). It does so by outlining how GIS data can be aggregated from multiple sources, which are often scattered and siloed, into one platform to use for sub-national energy planning.

Introduction

Expanding energy access effectively requires integrated energy planning and access to transparent analytical tools and data. The spatial dimension is important for energy planning as several data related to energy demand and supply vary from one geography to another based on factors such as socio-economic characteristics, energy resource availability, and proximity to power infrastructure. Geospatial data become even more relevant in connecting planning with realities on the ground and in visualising and analysing energy-related datasets to come up with practical, location-specific solutions to increase energy access.

Energy planning in Kenya is given high priority and is embedded in the law. The government ratified the Energy Act in 2019, requiring that all 47 county governments develop a County Energy Plan (CEP) building on local, geospatial data (Kipkemoi 2024). These CEPs are in turn expected to inform the Integrated National Energy Plan (INEP).

Access to complete, timely, accurate, reliable, and quality data and information on energy will be key to developing an effective INEP. These data are not only valuable to the energy sector, but across many other sectors of the economy at the county, national, and international levels.

However, the energy sector in Kenya experiences capacity gaps in terms of data management. Specifically, there is no clearly defined framework or guidelines for data collection, collation, analysis, interpretation, storage, and use at the national or county levels. There are also infrastructural and institutional barriers that affect data collection, analysis, sharing, and use at the national and county levels. Kenya's Ministry of Energy and Petroleum (MoEP) lacks access to software to integrate and harmonise national and county data in one centralised platform. Other challenges include those related to data security, data quality, a shortage of skilled big data professionals and energy systems analysts, inadequate financial resources for data management, and the lack of a centralised data repository (MoEP 2023). This has led to uncoordinated sharing of existing studies, data, and information by the industry players. Most counties also lack sufficient capacity to develop their CEPs. All these missing inputs are key to developing proper, data-informed energy plans which offer clear, practical, and context-specific solutions for the many counties in Kenya that have very poor energy access rates, resulting in low quality of life.

To support counties in the development of CEPs, this project established an open-source geographic information system (GIS) data platform which synthesises and analyses data from different databases. This publication explores how GIS data can be used for sub-national energy planning, using Narok County as a case study. Narok faces significant challenges in terms of energy access. In addition, the county is classified as one of the most underserved/marginalised counties in Kenya, characterised by low literacy rates, higher unemployment rates, limited access to energy, insufficient transport and communication infrastructure, limited access to social amenities, high poverty levels, negative climatic effects, and safety concerns. Despite electricity connectivity having increased—albeit modestly—from 6 percent of households in 2009 to 20 percent in 2018, more than 90 percent of the population relies on solid cooking fuels like charcoal and firewood which negatively impact household air quality and cause respiratory problems (KNBS 2019).

For this project, we used the Energy Access Explorer (EAE), the first open-source, online, and interactive geospatial platform that enables energy planners, clean energy entrepreneurs, donors, and development institutions to identify high-priority areas for energy access interventions (WRI 2019). This paper illustrates how energy planners can analyse credible and public data to align the demand for and supply of energy while creating custom analyses to identify and prioritise areas where energy markets can be expanded.

It also describes how this project used the Open Source Spatial Electrification Tool (OnSSET) to evaluate the least-cost technology mix that would meet the goal of universal electrification in different settlements of Narok County by 2026. Finally, it includes an affordability analysis of the identified pathway to evaluate whether target users would be able to afford the proposed solutions when rolled out.

This publication underscores the importance of incorporating GIS data, methodologies, and analytics in energy planning at the sub-national level using the case study of Narok County.

Methodology

In developing the Narok County Energy Plan, we relied on the MoEP's draft INEP Framework, which was produced through a collaborative process involving all energy entities and departments and other key stakeholders. The framework guides national energy service providers and county governments in creating energy plans that feed into the INEP. It highlights important topics that should be included in an energy plan, including energy sources, energy access, energy efficiency and conservation, bioenergy, and electricity (MoEP 2020).

The INEP Framework provides the following guidelines regarding county governments' responsibilities in developing their energy plans:

- Prepare CEP and submit it to the cabinet secretary for incorporation into the INEP. Use the template given in part five of the INEP Framework to prepare the CEP.
- Follow up on data gaps and ensure adequacy of information and data in the CEP.
- Collaborate with national energy service providers during planning and implementation of energy projects.
- Consult with other relevant national energy service providers to get data.
- Provide resources for implementation of the CEP.
- Build the energy planning capacity of their staff.
- Monitor and report on implementation progress.

County engagement process

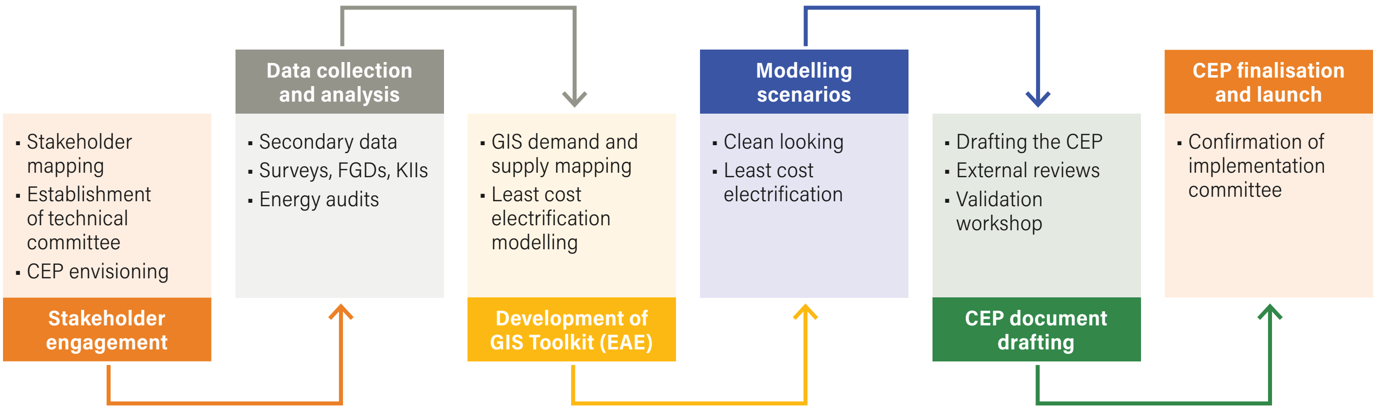
Developing the CEP for Narok County required extensive engagement with the county government and other stakeholders in the energy ecosystem in Narok to understand the county's unique needs that would need to be met by the plan; create working groups with various roles in the delivery of the CEP; collect relevant data to support the process; develop a GIS toolkit with various tools for processing, storing, and analysing these datasets; model various pathways of achieving universal access; validation with various stakeholders including community members and county government officials and technical partners; and draft the CEP using the findings from this process. The following paragraphs outline these steps in more detail.

The county government of Narok developed the CEP with technical assistance from Strathmore Energy Research Centre and World Resources Institute (the project team). A technical working group (TWG) was created which included the project team and officers from the county government's Department of Environment, Energy, Water, and Natural Resources, and was chaired by the director of that department. The County Energy Planning Committee—chaired by the county executive committee member in charge of the Department of Environment, Energy, Water, and Natural Resources, who was assisted by the chief officer—provided overall oversight and policy guidance to the TWG.

We developed the CEP following the procedure highlighted in Figure 1 and outlined here:

1. **Stakeholder engagement:** We conducted stakeholder mapping and engagement to obtain relevant data and information that would be used to develop the CEP. An additional goal was to develop relationships among departments in the Narok County government and with external stakeholders that would support future county energy planning. We engaged the national government through the Ministry of Energy and Petroleum to understand policy developments and projects being implemented and to obtain data. Other stakeholders engaged included Kenya Power; the Energy and Petroleum Regulatory Authority; Rural Electrification and Renewable Energy Corporation; Kenya Off-Grid Solar Access Project-Narok; Kenya National Bureau of Statistics (KNBS); and members of the private sector including non-governmental organisations (e.g. SNV, conservancies) as well as members of the community through surveys (targeting households, small and medium-sized enterprises [SMEs], institutions) and focus group discussions (men, women, youth, persons

Figure 1 | **CEP engagement process**



Note: CEP = County Energy Plan; FGD = focus group discussion; KII = key informant interview; GIS = geographic information system, EAE = Energy Access Explorer.
Source: Authors.

living with disabilities, cooperatives, and SMEs, among others). We also engaged other entities supporting counties in the development of energy plans, such as the Sustainable Energy Technical Assistance Project, to share ideas and insights on how to standardise the CEP development process in the country. This engagement was continuous throughout CEP development.

2. **Data collection:** We kicked off the data collection process by building consensus on the minimum data needs. Coordination was enhanced by developing and sharing a comprehensive and dynamic data wish list with the key stakeholders mentioned above. This was followed by secondary data collection from global, national, and sub-national reports and databases available in the public domain. To verify data from secondary sources and fill in identified gaps, we used elaborate surveys to collect quantitative data across the county focusing on the ward level. We conducted surveys on sampled households, educational institutions, health care facilities, and SMEs. We undertook sampling using Cochran's formula (MRL n.d.) to ensure statistical significance, and we administered the surveys using the KoboCollect application installed on Android-powered devices. The latter provided an efficient way of getting input data at increasing levels of granularity, covering households (rural and urban), institutions, and productive uses of energy segments. We programmed data-quality checks into the questionnaires using skip logic to ensure only relevant questions were asked based on answers to previous questions. For mapping purposes, each of the questionnaires featured a GIS prompt that collected the coordinates of households and premises interviewed. We collected additional quantitative data through both general energy audits and walk-through energy audits. We considered only county offices and county-managed facilities such as health care facilities and the water treatment plant for energy audits.

   We also collected qualitative data through 13 key informant interviews and 16 focus group discussions. The semi-structured key informant interviews were carried out with six county department officials, two cooperative society officials, two conservancy officials, and three energy practitioners. With these interviews, we aimed to understand county planning processes, plans, and community/business energy needs and priorities. We applied the same approach to focus group discussions but, as a group, focused on obtaining indepth understanding of community needs and aspiration. The focus group discussions involved productive use of energy segments as well as different gender and social inclusion groups. This added nuance to the survey and secondary data collected by the other methods by providing local insights, and enabled us to prioritise intervention projects and data related to people's willingness and ability to pay.

3. **Least-cost electrification and clean cooking modelling** were informed by the outputs of the data collection. We modelled scenarios for Narok County's future electricity supply and demand using OnSSET. We undertook clean cooking

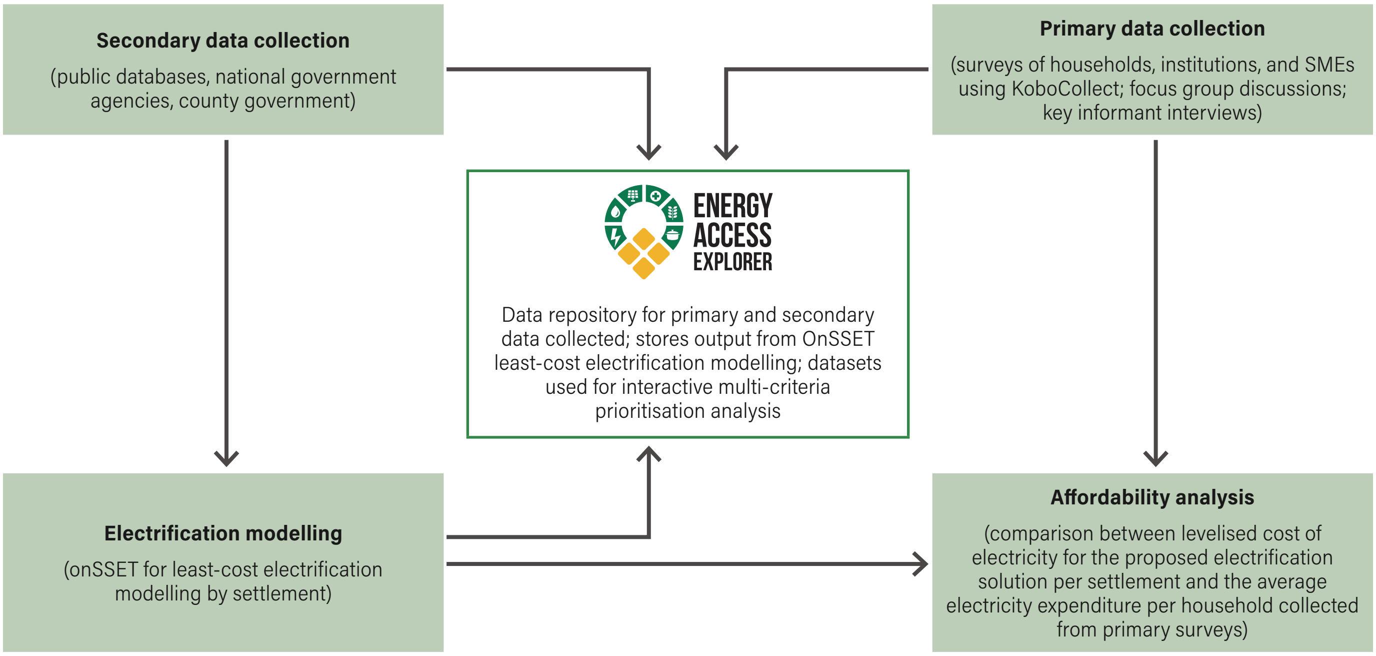
modelling using the Low Emissions Analysis Platform (LEAP) tool which considered firewood, charcoal, biogas, and liquefied petroleum gas (LPG) as fuel options for cooking. OnSSET is a bottom-up GIS-based toolkit for identifying least-cost technological options for electrifying unserved areas. LEAP is a widely used software tool for energy policy analysis and climate change mitigation assessment, developed by the Stockholm Environment Institute. LEAP can also analyse the emissions patterns of local and regional air pollutants and assess strategies to address short-lived climate pollutants, making it well-suited for studies on the climate co-benefits of local air pollution emissions reduction and vice versa (SEI 2017).

4. **Development of a GIS toolkit:** The CEP also involved the development of a customised version of EAE.
5. **Gender equity and social inclusion** (GESI) was considered throughout the project, from obtaining gender-disaggregated data and understanding the unique challenges and opportunities facing marginalised communities to capacity building—so the county government could consider GESI in policymaking and reporting—and presenting GESI disaggregated findings.
6. **CEP drafting:** The CEP was drafted in line with the INEP Framework. The inputs included analysed data collected through a literature review, primary data collection, an energy resources assessment, and electricity and clean cooking modelling.
7. **Validation of results:** We validated our results for the CEP through presentations made to county government officials, community members who had provided data, and development partners involved in energy planning for the county. The presentations were made during online working group meetings and in-person workshops where participants gave feedback that enabled the team to produce the first CEP draft. The first draft was then reviewed by a team of selected energy experts engaged in energy planning and Ministry of Energy and Petroleum staff, leading to the production of the final draft.
8. **Capacity building:** County officials underwent capacity building to equip them with the required skills to fully engage in the development of the CEP. The capacity building provided county officials with the skills needed to review the current CEP and develop future CEPs on their own as required by the Energy Act of 2019. Capacity building was undertaken with three groups of stakeholders: First, chief officers and directors of all the departments within the county took an introductory training on energy planning and policy. This training ensured trainees understood the unique role of energy as an enabler of service delivery. The technical working group received an additional training focused on the fundamentals of energy planning, with the goal of equipping the trainees with knowledge about the tools and methods used for energy planning. Finally, county officers in the technical working group participated in the entire process of CEP development as part of energy planning skills development.
9. **Integration of county energy planning into the County Integrated Development Plan (CIDP):** The development of this CEP took into consideration insights as well as plans and projects provided by all the county departments that require energy as an enabler. This CEP also identifies prioritised programmes and projects for implementation in collaboration with other departments. When this CEP was completed, the county was beginning its sectoral workshops which lead to the development of the CIDP. We suggested to the county to include the recommended projects and programmes within the CEP into the CIDP.

Figure 2 summarises the process the team undertook in drafting the Narok CEP.

As can be seen in Figure 2, we employed both secondary and primary GIS data collection approaches and tools to inform the analytical outputs that fed into the CEP. We uploaded the collected data into EAE, and used some in the least-cost electrification modelling through OnSSET, with outputs from OnSSET also uploaded into EAE. Furthermore, we used outputs from OnSSET alongside some indicators collected from the primary data collection to perform an affordability analysis of the proposed least-cost electrification solutions.

Figure 2 | **Flow chart illustrating the process that was used for collecting, storing, analysing, and applying GIS data in the Narok CEP development process**



Note: GIS = geographic information system; CEP = County Energy Plan; EAE = Energy Access Explorer; OnSSET = Open Source Spatial Electrification Tool; SMEs = small and medium-sized enterprises.

Source: Authors.

The next sections of the methodology explain in more detail the specific aspects where the collection and application of GIS data played a crucial role in the development of the Narok CEP.

Data collection (primary and secondary)

The primary data collection came after an extensive collection of secondary datasets obtained through a literature review, credible public databases, government reports, and data sent directly from various data providers including the private sector and various ministries and parastatals after the team requested them.

These data were collected based on a wish list (see Appendix A, Figure A-1) which was prepared after consulting with stakeholders in the energy ecosystem in Narok County to identify the datasets and their formats, granularity needed, date of content needed (how recent), and sources for the various chapters or sections to be covered in the CEP. The data wish list in Appendix A outlines the data sources and repositories identified from the secondary data collection, the description of the data sources, and links to access the data, if available. Attention was given to using sources that were peer reviewed and/or from a credible government source or website or a credible publicly available database. The data wish list covered themes including spatial data on energy demand and supply; techno-economic parameters for the least-cost electrification modelling in OnSSET; energy access status and usage in households and across various institutions; productive uses of energy; energy efficiency assessment for households, public buildings, and institutions; and bioenergy demand and consumption. Major gaps in the data wish list that required additional primary data collection included information on current energy access usage patterns across households and institutions, willingness to transition to cleaner fuels, energy appliances used and efficiency levels, and monthly expenditures on energy.

We identified gaps in the data wish list during the secondary data collection process where we could not find certain critical datasets. Primary data collection through surveys covering households, institutions (schools and hospitals), government buildings, SMEs, and industries filled these gaps.

We administered the surveys using KoboCollect, a mobile application within the KoboToolbox database. A computer-aided personal interviewing tool based on Open Data Kit (ODK), KoboToolbox is the de facto open-source standard for mobile data collection. The toolbox is fully compatible and interchangeable with ODK but delivers more functionality such as an easy-to-use form builder, question libraries, and integrated data management. For this survey, we employed the humanitarian edition of KoboToolbox, a joint initiative among the United Nations Office for the Coordination of Humanitarian Affairs, Harvard Humanitarian Initiative, and International Rescue Committee (Colozzi 2023).

We defined the four questionnaires in Microsoft Excel and deployed them on the data manager's KoboToolbox account, which was then shared with the enumerators' accounts, granting the latter group limited permissions (to only submit data) as a measure to enhance data security and privacy. KoboToolbox is a widely used data collection platform with sophisticated data protection policies that are favourable for field surveys that involve offline mobile data collection in remote villages. For this reason, and other pragmatic conveniences including ease of use, we chose to use the platform for the survey.

We used GIS methodology to randomly identify target households and institutions across the six sub-counties of Narok to get enough responses to meet the desired sample sizes: 612 for households, 838 for SMEs, 20 for health facilities, and 38 for learning institutions. For mapping purposes, each of the questionnaires featured a GIS prompt field that collected coordinates (latitude, longitude, and altitude) of the households, learning institutions, SMEs, and health care facilities to the desired precision of five metres.

Enumerators were locally recruited from across the region where interviews were to take place and were rigorously trained on how to use KoboCollect to gather survey data as well as on best practices for data collection such as the consenting process and how to maintain enumerator neutrality.

They were also thoroughly taken through the four questionnaires in detail and taught the purpose and objective of these surveys until the trainers were satisfied with the enumerators' grasp of the basic yet fundamental elements and requirements of the survey. Local enumerators are knowledgeable about the prevailing socio-political and security conditions in the target areas and were therefore considered most suitable for the exercise. Table G-1 in Appendix G shows a copy of the questionnaire used for primary data collection from households to identify their energy usage patterns and needs.

Before the actual data collection, we tested and piloted survey tools to ensure they were working as expected and to acclimatise the enumerators to the data collection activities and nuances of the environment. We then updated the survey tools using Excel-defined KoboToolbox codes to correct the weaknesses spotted in the field and adjusted them to achieve the desired robustness. These identified weaknesses were mostly errors in sentence structure or spelling, the question choice list, or skip logic. The codes were redeployed in the database and assigned appropriate version numbers for version control and document update tracking. Figure B-1 in Appendix B shows KoboCollect's user interface.

We then collected data across the six Narok sub-counties. The surveys were carried out by experienced and well-trained enumerators.

On average, household interviews lasted 75 minutes; SME interviews, 39 minutes; health care facilities, 60 minutes; and learning institutions, 90 minutes.

We performed descriptive data analysis on all four datasets from the four questionnaires and all the variables in the questionnaires to unlock the specific analytics, patterns, and insights needed to develop the CEP. This entailed reporting in tables and graphs. Most analyses were disaggregated by rural and urban split as well as administrative unit including sub-counties, wards, locations, and sub-locations. We tabulated frequencies and percentages for categorical variables, while we reported the mean, standard error of the mean, 95 percent lower and upper limit of the mean, and standard deviation for numeric variables. For categorical variables, we reported the frequency followed by the percentage. Unless otherwise noted, all percentages add up to 100 percent column-wise. The analysis also includes a bit of hypothesis testing at a 95 percent confidence level to explore any significant discrepancies within an indicator across the stratification variable such as rural-urban split, gender, and administrative unit.

Challenges in the data collection process

1. Obtaining secondary datasets from multiple data sources, which mostly operate separately and with different mandates, presented challenges. In cases where the datasets were confidential and proprietary, this process involved reaching out to the owners of the datasets explaining the reason for data collection and how we would use the data.

In addition, since the datasets were from different sources, we needed to standardise the data so they would have the same format (e.g. coordinates system, resolution, data type). This process was, however, made simpler through an automated data processing functionality that was added into the back end of EAE.

The data collection process was time-consuming. The project team spent an initial two months collecting secondary data, though more data were collected and refined throughout the project as needed.

Secondary data collection can be streamlined by having one centralised location where all stakeholders can contribute data and where datasets can be stored.

2. Collecting primary data when they could not be obtained through secondary sources was both time and resource intensive. As part of the data collection process, the project team resorted to collecting some data physically from the field using mobile data collection tools. We conducted household and institutional surveys as well as focus group discussions with sampled respondents across the county. This was challenging as it required travelling long distances from one point to another, often along rough roads, to collect these datasets. While both time and resource intensive, the process was ultimately rewarding due to the diverse and rich datasets collected, which informed the findings added to the CEP. Primary data collection, synthesis, analysis, and harmonisation took six months.

Developing the Energy Access Explorer for Narok County

Developing EAE for Narok first involved using a new functionality developed for EAE called 'inherit,' which essentially clips the datasets to create a smaller or more granular stand-alone version of EAE covering a geographic area smaller than the one which already exists in EAE.

In the case of Narok County, the existing energy demand and supply data in EAE available at the country level for Kenya was used to extract the data specific to Narok County to create an EAE version for Narok with only Narok-specific datasets. This included but was not limited to location-specific resource availability and infrastructure data to represent energy supply, demographic data, and data on social and productive uses of energy to visualise demand for energy services.

We then customised EAE version for Narok County with additional data collected from a separate exercise to map out the productive use of energy opportunities in agriculture and other critical datasets from the secondary data collection exercise as well as outputs from the primary data collection exercise.

We then analysed these datasets using some of the spatial analysis tools within EAE, including multi-criteria analysis, overlays, filters, and buffer zones, to help users identify and prioritise areas where energy access can be expanded within the county to inform energy planning efforts.

The next sections further describe the functionalities of EAE and provide use cases in energy planning. This is followed by practical examples and sample output analysis results from the Narok version of EAE, showing how EAE can be used for energy planning in the county.

Application of EAE in energy planning

EAE synthesises several geospatial data to visualise and analyse **demand** for energy services such as from the following:

- Demographics
  - Population density (people/square kilometre [km^2])
  - Relative wealth index (scale ranging from –2 to 2, with 0 representing average household wealth)
  - Asset ownership (e.g. percentage of households that own a particular asset)
- Social and productive uses
  - Schools (name, type, proximity in km)
  - Health facilities (name, type, proximity in km)
  - Agricultural activities (e.g. crop production in metric tons, percentage crop cover, rainfed versus irrigated cropland)

Similarly, EAE incorporates data to represent current or potential **supply** of energy services. These include the following:

- Resource availability including wind speed (metres/second), solar—global horizontal irradiation (kilowatt-hours per square metre; kWh/m^2), small-scale hydropower (head, potential capacity, proximity in km)
- Power infrastructure including transmission (voltage, proximity in km), distribution (voltage, proximity in km), and generation networks (name, type, capacity, proximity in km)

Furthermore, it incorporates important data on the following:

- Environment, such as protected areas (name, type, size in km^2) and forest cover (percentage forest cover)
- Access to finance such as finance service providers (type, ward location, proximity in km)
- Other categories such as land cover (percentage of different land classes)

EAE enables all users to do a multi-criteria decision analysis on the fly and identify high-priority areas where access to energy should be expanded.

Beyond its visualisation and analytical capabilities, EAE functions as a dynamic geographic information system and data repository which reduces software engineering and data transaction costs for both data providers and users. Its unique back-end infrastructure comes with an easy-to-navigate content management system and allows administrative users with limited or no GIS and programming expertise to add data and metadata in a simple manner.

Using EAE in electrification planning

Electrification prioritisation analysis example using EAE for Narok County

As has been mentioned, we customized EAE for Narok County as part of developing Narok's CEP. EAE can be used to generate interactive, on-the-fly spatial and quantitative datasets to show where energy demand is—and supply is lacking—based on the unique perspectives of each user.

The example below shows a prioritisation analysis for a scenario where the county wants to electrify schools and hospitals that are off-grid. This scenario is particularly relevant for Narok County, which needs to improve service delivery for schools and hospitals. EAE is used here to indicate areas in Narok County which are far away from the main electricity distribution lines, are close to schools and health care facilities, have sufficient population density present, and have good solar potential.

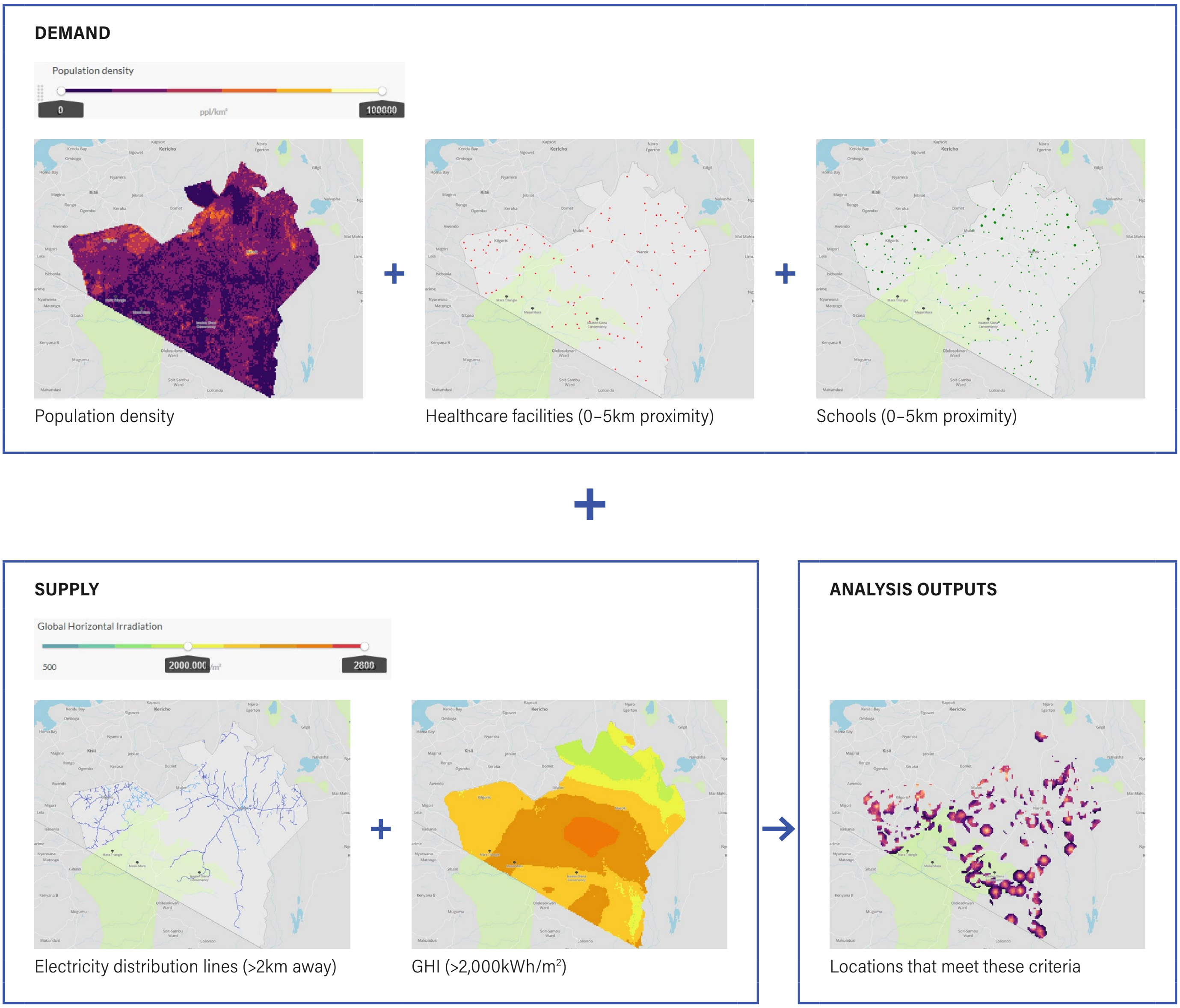
Datasets loaded on both demand and supply categories, as well as the filters used, are shown in Figure 3.

Figure 4 shows EAE's analysis results for the priority areas determined using the criteria defined in Figure 3.

Figure 5 shows additional information on one of the top 20 locations identified as having high energy access potential (shown in Figure 4) as per the criteria set.

Figure 6 shows the same location identified in Figure 5 as compared with a satellite image to confirm the analysis findings.

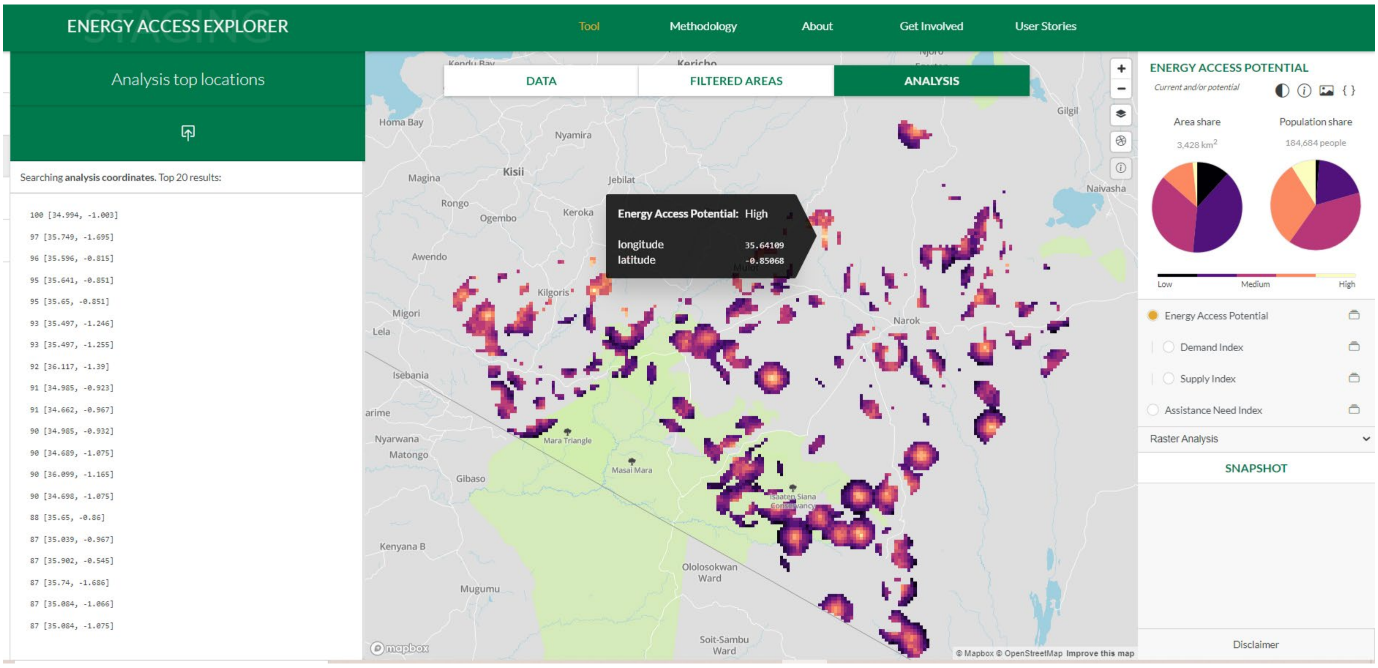
Figure 3 | **Examples of Energy Access Explorer's high-resolution, multi-criteria prioritisation analysis**



Notes: This analysis identifies priority areas which we defined as those close to health care and educational facilities, far from the power network, and with significant solar potential. This is a sample analysis. Users can combine more than 25 geospatial datasets and generate custom prioritisation analyses, maps, and reports based on their own criteria and analysis preferences. km = kilometre; GHI = global horizontal irradiation; kWh/m² = kilowatt-hour per square metre.

Source: Authors.

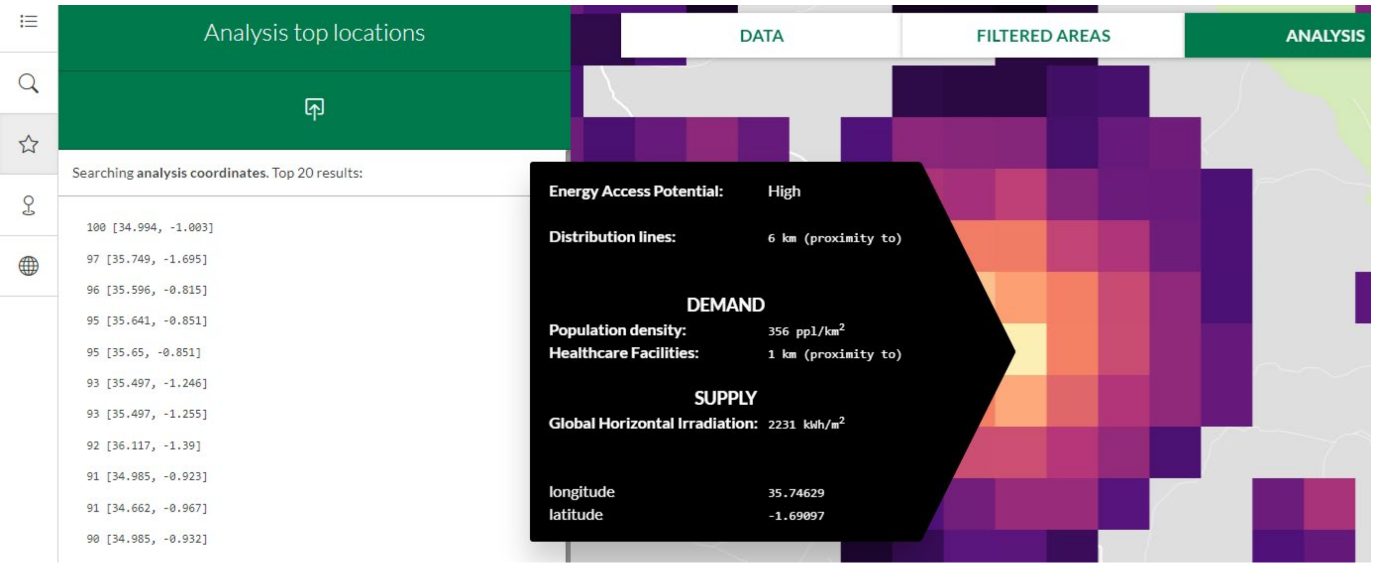
Figure 4 | Analysis results based on the criteria defined in Figure 3



Note: This figure displays the total population living in the filtered areas shown in the map as 184,684. The criteria used to show the top locations in this analysis are that the locations should be close to health care and educational facilities, be far from the power distribution network, and have good solar potential. The Energy Access Explorer also lists the top 20 priority areas based on user-defined criteria.

Source: Authors. Analysis results from the Energy Access Explorer.

Figure 5 | Additional level of detail for one of the top 20 priority locations based on user-defined criteria



Note: For this location, the population density is 356 people/square kilometre (km^2); proximity to the closest health care facility is 1 km; the distance to the closest distribution line is 6 km, indicating that this area is not connected to the grid; and the global horizontal irradiation is 2,231 kilowatt-hours per square metre, illustrating significant potential for solar energy.

Source: Authors. Analysis results from the Energy Access Explorer.

Figure 7 shows another top location with high energy access potential as identified in EAE compared with an underlying satellite image.

Analysis results outputs

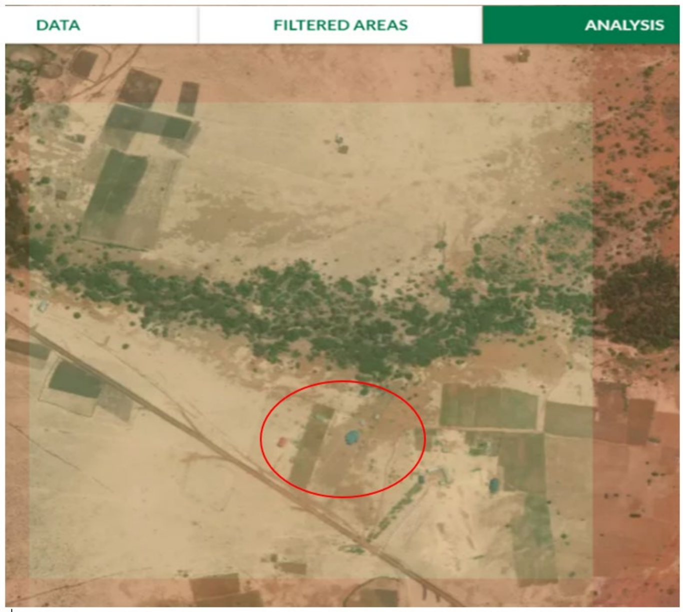
EAE uses multi-criteria analysis to identify areas of interest to expand energy access where it's needed most. Users combine datasets on energy demand and supply, apply user-defined filters that factor in proximity, and weight the datasets to identify locations that are ideal for expanding energy access such as for productive uses of energy.

One of EAE's analytical outputs is a high-resolution geospatial map that shows the areas that meet the criteria for the analysis. For example, in the case of Narok County, areas shown in the analysis results are close to productive uses of energy (e.g. schools, health care facilities), are far from electricity distribution lines, and have great potential for solar energy.

In addition to the map, the panel on the right of EAE interface displays summary statistics such as total area and population share for areas that meet these criteria. Total area and population share are further broken down per different analysis indices such as the Energy Access Potential Index, Demand Index, Supply Index, or Assistance Need Index.

The Energy Access Potential Index identifies areas with higher energy demand and supply which are characterised by higher index values. It is an aggregated and weighted measure of all selected datasets under both demand and supply categories. The Demand Index identifies areas with higher energy demand while the Supply Index identifies areas with higher energy supply based on datasets under energy demand and supply, respectively. The Assistance Need Index identifies areas where market assistance is most needed, which are characterised by higher index values. This index is an aggregated and weighted measure of selected datasets under both demand and supply categories indicating high energy demand, low economic activity, and low access to infrastructure and resources. These indices range from low to medium to high and are coloured differently on the map with areas with high potential tending toward bright yellow and areas with lower potential tending toward black.

Figure 6 | **Top locations identified compared with satellite imagery**



Note: The image shows the same location identified in Figure 5. You can see some buildings enclosed in the red circle toward the bottom right which could be the health care facility identified to be 1 km away.

Source: Authors. Analysis results from the Energy Access Explorer.

Figure 7 | **Another priority location example**

Note: This location has a number of houses (examples circled in red) with potential to be electrified as well as farms (circled in yellow) that could benefit from productive uses of energy for agriculture.

Source: Authors. Analysis results from the Energy Access Explorer.

For the Energy Access Potential Index (which is the default), areas with higher energy demand and supply potential are characterised by higher index values, making these the areas it would make sense to start electrifying first. More details on the methodology and these indices can be found in the 'Energy Access Explorer: Data and Methods' technical note (Mentis et al. 2019).

Finally, you can export this analysis as a report by clicking on 'REPORT' at the top of the results panel on the right to see summary graphs, visualise the summary table and export, and view the report as a PowerPoint presentation.

Through the dynamic nature of EAE, visualisations and prioritisation analysis are updated in real time once new or updated data are integrated in the platform. This saves EAE users a significant amount of resources and time when it comes to generating or updating a geospatial prioritisation analysis.

More details on EAE's functionalities are outlined in Appendix C.

Least-cost electricity modelling using OnSSET

Considering Narok's low electrification and sparse population densities, it is essential that off-grid technologies like solar home systems and mini-grids are considered alongside the grid as possible energy supply solutions. This section illustrates the results of least-cost electrification modelling using OnSSET which sought to develop least-cost electrification solutions for Narok between 2022 and 2026. We adopted this model horizon based on guidance in the INEP. In this section, we discuss our analysis of current data and then present electrification scenarios with the results obtained.

Baseline data

The electricity system infrastructure in Narok consists of the national grid which comprises medium-voltage (MV) and high-voltage (HV) lines, substations, transformers, and power plants. Figure 8 highlights this infrastructure (both existing and planned) together with the locations of some mini-grids within Narok County. Table 1 outlines the length of existing MV and HV lines in Narok together with the number of mini-grids.

We integrated additional baseline datasets on energy demand and supply into EAE.

Electrification modelling

We modelled scenarios for Narok County's future electricity supply and demand using OnSSET.

OnSSET is a bottom-up GIS-based cost toolkit that runs on Python-based code for identifying least-cost technological options for electrifying unserved areas.[1] It explores scenarios for expanding access through an analysis of on-grid, off-grid, and mini-grid systems and the associated investment needs. An electrification algorithm identifies and selects the technology configuration with the lowest levelised cost of electricity for a given settlement.

The levelised cost of electricity (LCOE) from a specific source represents the final cost of electricity required for the overall system to break even over its lifetime.

Equation 1 gives the formula we used to calculate LCOE for a particular technology:

Equation 1

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

I_t: Investment expenditure for a specific system in year t

$O\&M_t$: Operation and maintenance costs

F_t: Fuel expenditures

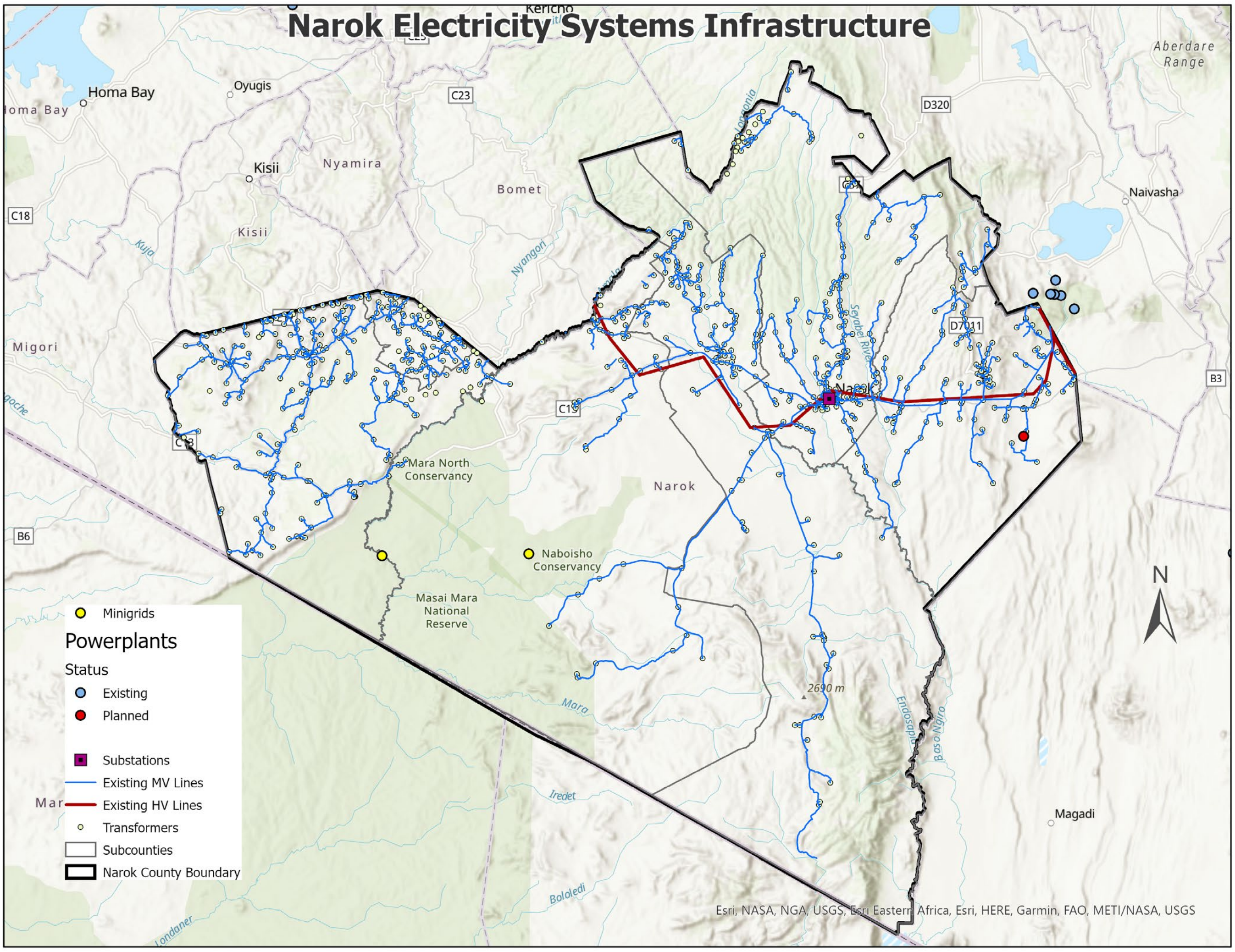
E_t: Generated electricity

r: Discount rate

n: Lifetime of the system

The electrification options in this analysis are divided into three main categories: grid connected, mini-grids (solar, wind, hydro), and stand-alone systems (e.g. solar home systems). We calculated the cost of generating and distributing electricity for all grid and off-grid technologies according to renewable energy resource availability (e.g. global horizontal irradiation), proximity to grid and the technical and economic parameters of generation

Figure 8 | **Electricity system infrastructure**



Note: MV = medium voltage; HV = high voltage.
Source: Authors.

technologies (e.g. capacity and capital cost factors for all components of the technologies). For mini-grids, we added an additional cost for the distribution network. Then for each settlement, we selected the most cost-effective off-grid technology.

As OnSSET is a GIS-based tool, it requires data to be in a geographical format. For this study, we used the following spatial data:

- Distribution of HV lines (current and planned)
- Distribution of MV lines
- Population distribution
- Road network
- Global horizontal irradiation

Table 1 | **Summary of existing electricity infrastructure in Narok County**

INFRASTRUCTURE	STATUS	COUNT OR LENGTH (KM)	GENERAL LOCATION
High-voltage lines[a]	Existing	157.5 km	Across the county
Medium-voltage lines[a]	Existing	2,043 km	Across the county
Substations[b]	Existing	1	Narok Town
Transformers[c]	Existing	842	Across the county
Mini-grids[d]	Existing	3	Talek, Mara River

Note: km = kilometre.
Sources: a KPLC 2017a. b KPLC 2017b. c KPLC 2017c. d CLUB-ER and Carbon Trust 2019.

- Locations of substations and distribution transformers
- Wind speed
- Location of small hydropower potential sites
- Land cover
- Nighttime light
- Elevation and slope
- Administrative boundaries

We processed these layers using GIS software to create an input file (table) for the OnSSET model. We also used additional non-GIS data as the model input parameters. These are described in Appendix D.

After consulting with county officials and various stakeholders, we developed multiple scenarios at both the county and subcounty levels to model the least-cost technology option to achieve universal electrification by 2026. Table E-1 in Appendix E explains in more detail alternative scenarios made possible through the OnSSET modelling tool. We derived tiers of access from the multi-tier framework, which acknowledges that energy access is not binary. It is based on the principle that people will get access to different energy services as their access level or consumption grows. Table 2 shows the growing access to energy services as energy access increases depicted by the multi-tier framework.

It should be noted that these scenarios did not explicitly consider data on the productive use of energy (PUE) because geolocated information on PUE was not available at the time this plan was developed and a county-wide data collection exercise to incorporate information on PUE would have gone beyond the time horizon of this study. We therefore assumed that productive use would be able to connect to household supply. We set the base year for this analysis as 2022. OnSSET provides results for an intermediate year and a final year. We set the intermediate year to 2024 and the final year to 2026.

The three scenarios developed for this CEP—Domestic Electrification, Low Demand (Scenario 1); Domestic Electrification, High Demand (Scenario 2); and Domestic Electrification, High Demand, Forced Grid Intensification (Scenario 3)—are described in detail in Table 3 while the following sections describe the results obtained from modelling the scenarios.

Table 2 | **Multi-tier matrix for measuring access to household electricity supply**

		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Peak capacity	Power capacity ratings (in W or daily Wh)		Min 3 W Min 3 Wh	Min 50 W Min 200 Wh	Min 200 W Min 1.0 kWh	Min 800 W Min 3.4 kWh	Min 2 kWh Min 8.2 kWh
	Services		Lighting of 1,000 lmhr/day	Electrical lighting, air circulation, television, and phone charging are possible			
Availability (duration)	Hours per day		Min 4 hr	Min 4 hr	Min 8 hr	Min 16 hr	Min 23 hr
	Hours per evening		Min 1 hr	Min 2 hr	Min 3 hr	Min 4 hr	Min 4 hr

Note: W = watt; Wh = watt-hour; kWh = kilowatt-hour; hr = hour; Min = minimum; lmhr = lumen-hour.
Source: ESMAP 2015.

Table 3 | **Key assumptions for the modelled scenarios**

ASSUMPTION CATEGORY	SCENARIO 1: DOMESTIC ELECTRIFICATION, LOW DEMAND	SCENARIO 2: DOMESTIC ELECTRIFICATION, HIGH DEMAND	SCENARIO 3: DOMESTIC ELECTRIFICATION, HIGH DEMAND, FORCED GRID INTENSIFICATION	SCENARIO 3: DOMESTIC ELECTRIFICATION, HIGH DEMAND, FORCED GRID INTENSIFICATION (BROKEN DOWN AT SUB-COUNTY LEVEL)
Demand-side assumptions	▪ Normal population growth at 3.3% ▪ Tier 1[a] of electrification for rural consumers and Tier 4 for urban consumers ▪ 40% electrification rate in 2024 ▪ 100% electrification in 2026	▪ High population growth at 4% ▪ High electricity demand target (Tier 2 for rural areas and Tier 5 for urban areas) ▪ 40% electrification rate in 2024 ▪ 100% electrification in 2026	▪ High population growth at 4% ▪ High electricity demand target (Tier 2 for rural areas and Tier 5 for urban areas) ▪ 40% electrification rate in 2024 ▪ 100% electrification in 2026	▪ High population growth at 4% ▪ High electricity demand target (Tier 2 for rural areas and Tier 5 for urban areas) ▪ 40% electrification target in 2024 ▪ 100% electrification in 2026
Supply-side assumptions	▪ Low generating cost for the grid ▪ PV capacity cost as defined by the user ▪ Prioritisation of least-cost electrification technologies (grid, mini-grids, and solar home systems)	▪ High generating cost for the grid ▪ PV capacity cost reduced by 25% ▪ Prioritisation of least-cost electrification technologies (grid, mini-grids, and solar home systems)	▪ High generating cost for the grid ▪ PV capacity cost reduced by 25% ▪ Using grid electrification for areas that are within 2 km of the grid	▪ High generating cost for the grid ▪ PV capacity cost reduced by 25% ▪ Using grid electrification for areas that are within 2 km of the grid

Note: a Tiers of demand are used to approximate demand in rural and urban areas and not to define electrification solutions. See Table 2 for more. PV = photovoltaic; km = kilometre.
Source: Authors.

Scenario 1: Domestic Electrification, Low Demand

Figure 9 shows the recommended technology by settlement for Scenario 1 while Table 4 shows the capacity required for electrification.

In Scenario 1, the grid, stand-alone solar photovoltaic (PV), and solar PV mini-grids are the least-cost options for electrification. In the intermediate year, only the grid is considered to be the least-cost solution. This is because OnSSET starts with grid densification first and then extends electricity to non-electrified settlements until it is no longer feasible or least cost to do so. Finally, it considers off-grid solutions. Solar PV has the highest capacity at 2.9 megawatts (MW) even though no subsidy is applied to solar PV. This could be due to the lack of productive use as this scenario focused on domestic electrification. The sparse population density in Narok may have also contributed to this.

The investment costs required to implement this scenario are tabulated in Table 5. The total cost for deploying Scenario 1 is US$50.1 million. Fifty-five percent of this investment is allocated to grid expansion and densification.

Table 4 | **Capacity required for electrification in Scenario 1**

TECHNOLOGY	2024 (MW)	2026 (MW)	TOTAL (MW)
Grid	0.5291	0.0613	0.5904
Stand-alone PV	0	2.9912	2.9912
Mini-grid PV	0	0.0252	0.0252
Total (MW)	**3.6068**		

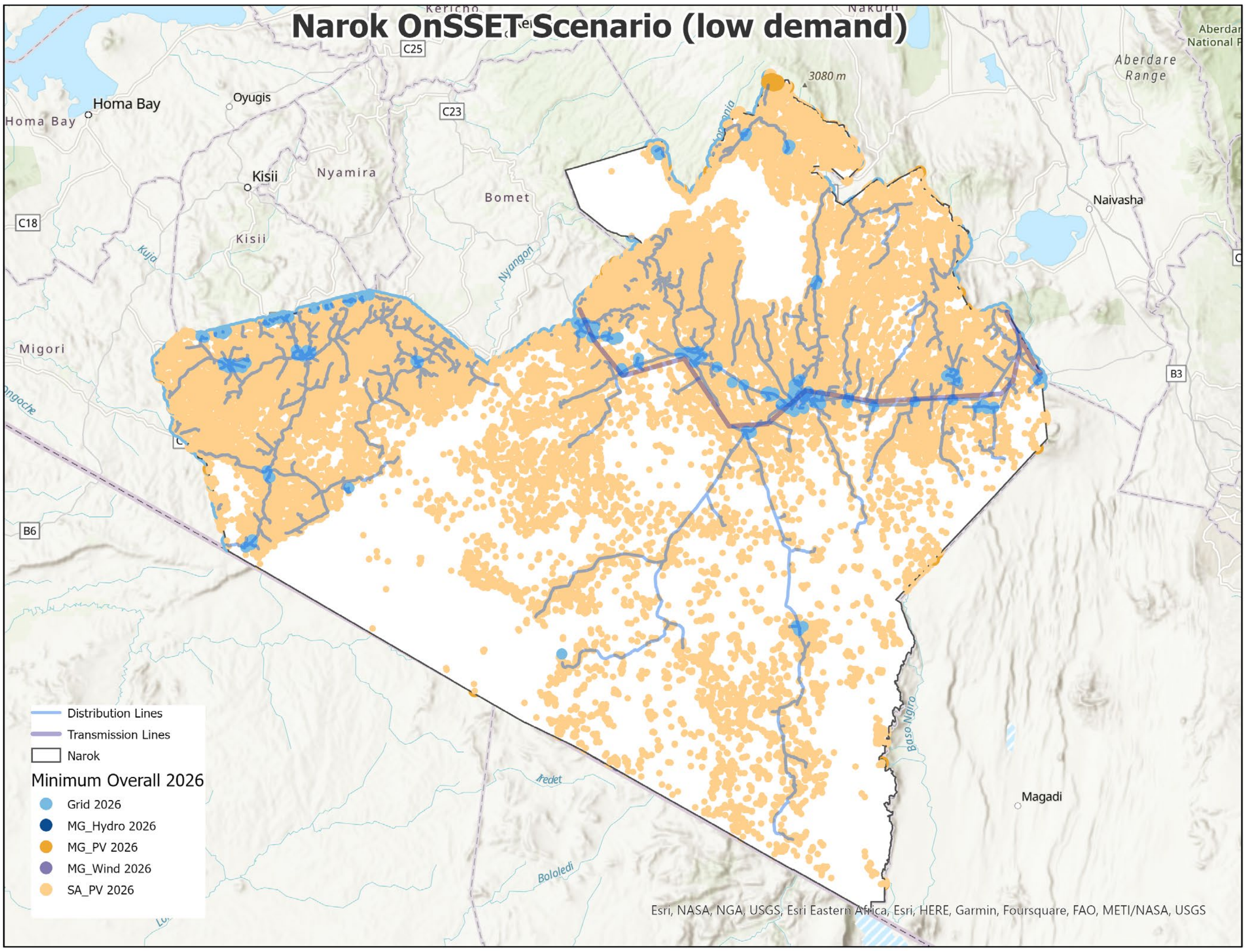
Note: MW = megawatt; PV = photovoltaic.
Source: Authors.

Table 5 | **Investment required for Scenario 1 in 2024 and 2026**

TECHNOLOGY	2024 (MILLIONS, $)	2026 (MILLIONS, $)	TOTAL
Grid	24.0	3.5	27.5
Stand-alone PV	0	22.4	22.4
Mini-grid PV	0	0.09	0.09
Total	**50.1**		

Notes: The costs cover both investment and operations & maintenance costs over the lifetime of the electrification technology. PV = photovoltaic.
Source: Authors.

Figure 9 | **Technology recommendations by settlement in 2026 for Scenario 1**



Note: Grid 2026 = Households for which the grid is the least-cost electrification solution in 2026; MG_Hydro 2026 = Households for which hydropower mini-grids are the least-cost solution in 2026; MG_PV 2026 = Households for which solar mini-grids are the least-cost solution in 2026; MG_Wind 2026 = Households for which wind-powered mini-grids are the least-cost solution in 2026; SA_PV 2026 = Households for which stand-alone photovoltaic (solar) is the least-cost solution in 2026; OnSSET = Open Source Spatial Electrification Tool.

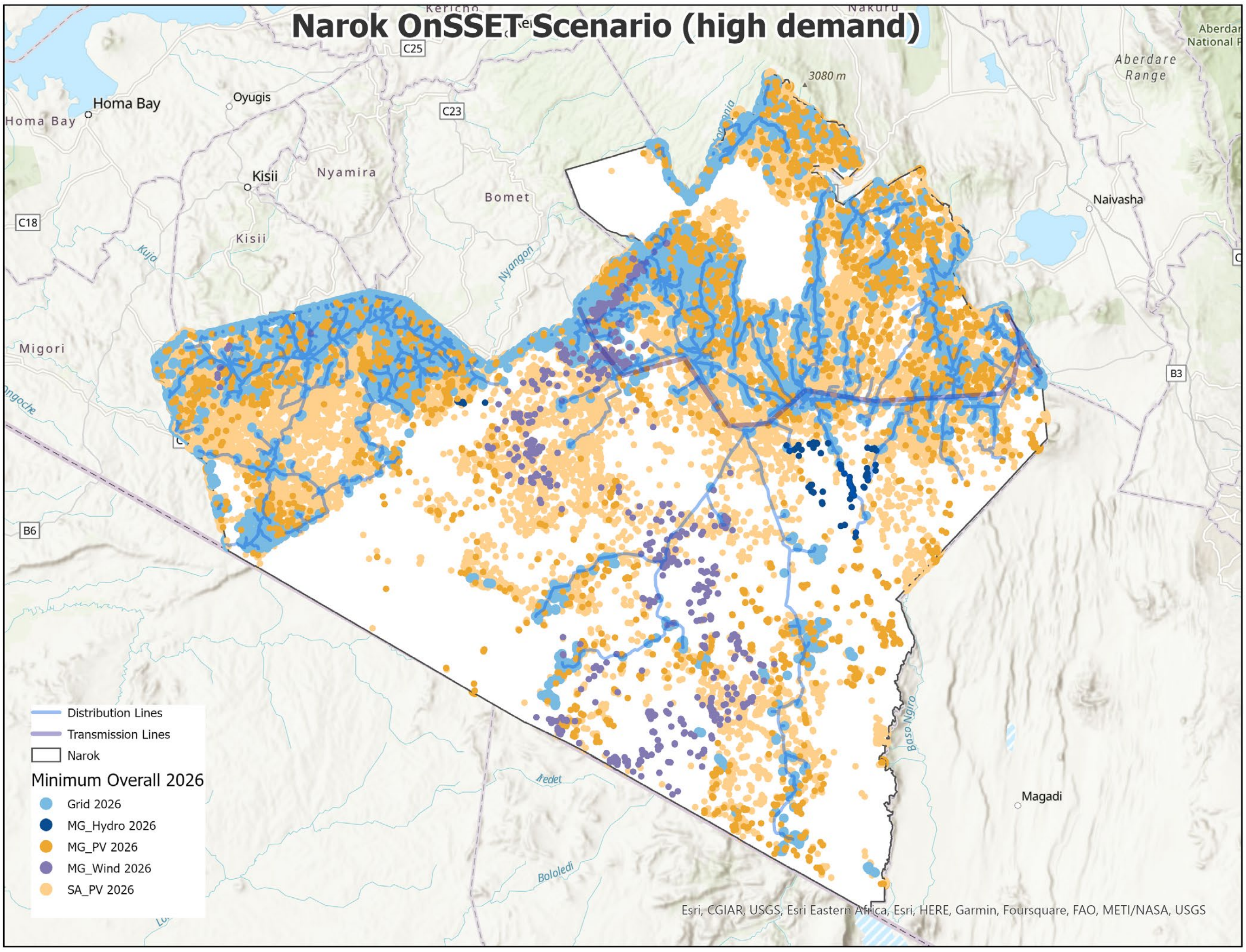
Source: Authors.

Scenario 2: Domestic Electrification, High Demand

Figure 10 shows the recommended technology by settlement in 2026 for Scenario 2 while Table 6 shows the capacity of technologies required for electrification.

Table 6 shows that the proposed technologies for Scenarios 1 and 2 are similar, with grid densification given as a priority for the intermediate year in both scenarios. However, Scenario 2 includes wind and hydro mini-grids by 2026. This indicates that the resources (investment costs) required for setting up mini-grids become commercially viable with higher populations. It should be noted that the model considers supply-side costs and not the end user costs of consumption. As such, while it may be cheaper to construct mini-grids, it has been proved that the costs of consumption for the end user could be several times higher than those for the grid, particularly when there is no productive use (Ogeya et al. 2021). Innovative financing models or subsidies through projects such as the Kenya Off-Grid Solar Access Project may therefore need to be applied where mini-grids are a least-cost option. Productive use of energy also needs to be promoted in areas where mini-grids are suggested to make the investments more sustainable in the long run while improving the livelihoods of the local communities.

Figure 10 | **Technology recommendations by settlement in 2026 for Scenario 2**



Note: Grid 2026 = Households for which the grid is the least-cost electrification solution in 2026; MG_Hydro 2026 = Households for which hydropower mini-grids are the least-cost solution in 2026; MG_PV 2026 = Households for which solar mini-grids are the least-cost solution in 2026; MG_Wind 2026 = Households for which wind-powered mini-grids are the least-cost solution in 2026; SA_PV 2026 = Households for which stand-alone photovoltaic (solar) is the least-cost solution in 2026; OnSSET = Open Source Spatial Electrification Tool.

Source: Authors.

Stand-alone diesel and diesel mini-grids are absent from the technology choices as the modelling considered only renewable energy solutions. The investment costs for this scenario are described in Table 7. As expected, they are higher than those for Scenario 1 because of the higher population to be electrified. When compared with the total installed grid capacity of Kenya, which is about 3,000 MW, the new capacity to achieve universal access to electricity though this scenario for Narok would need to add only about 2 percent of capacity to the national grid.

Table 6 | **Capacity of electrification technologies required**

TECHNOLOGY	2024 (MW)	2026 (MW)	TOTAL (MW)
Grid	13	15.6	28.7
Stand-alone PV	0	26.1	26.1
Mini-grid PV	0	9.8	9.8
Mini-grid wind	0	2.6	2.6
Mini-grid hydro	0	0.085	0.085
Total			**67.4**

Note: PV = photovoltaic; MW = megawatt.

Source: Authors.

Table 7 | **Investment required for Scenario 2 in 2024 and 2026**

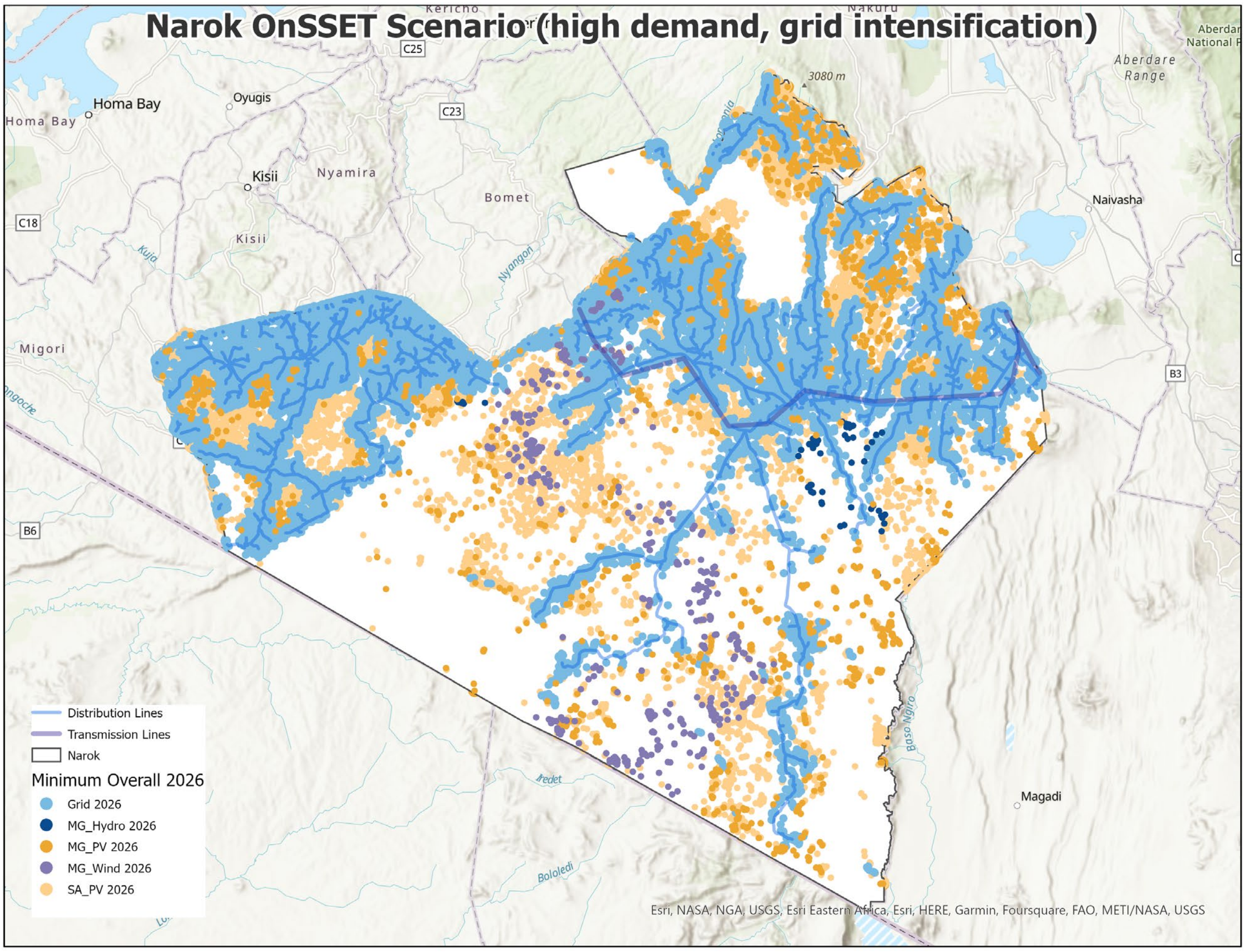
TECHNOLOGY	2024 (MILLIONS, $)	2026 (MILLIONS, $)	TOTAL
Grid	84.7	134.67	219.3
Stand-alone PV	0	125.3	125.3
Mini-grid PV	0	44.9	44.9
Mini-grid wind	0	8.9	8.9
Mini-grid hydro	0	0.53	0.53
Total	**399.2**		

Note: PV = photovoltaic.
Source: Authors.

Scenario 3: Domestic Electrification, High Demand, Grid Intensification

Scenario 3 forces grid electrification (intensification) in areas that are 2 km away from the grid regardless of whether it is a least-cost option. Figure 11 describes the recommended technology by settlement in 2026 for Scenario 3 while Table 8 shows the capacity of electrification technologies used. As expected, this scenario deploys significantly more grid electrification with a total of 34.8 MW compared with Scenario 2's 28.7 MW. This naturally causes a reduction in the deployment of other technologies like solar home systems and mini-grids as compared with Scenario 2. This reduction results in a decrease in overall capacity to 52.8 MW as compared with Scenario 2's 67.4 MW.

Figure 11 | **Technology recommendations by settlement in 2026 for Scenario 3**

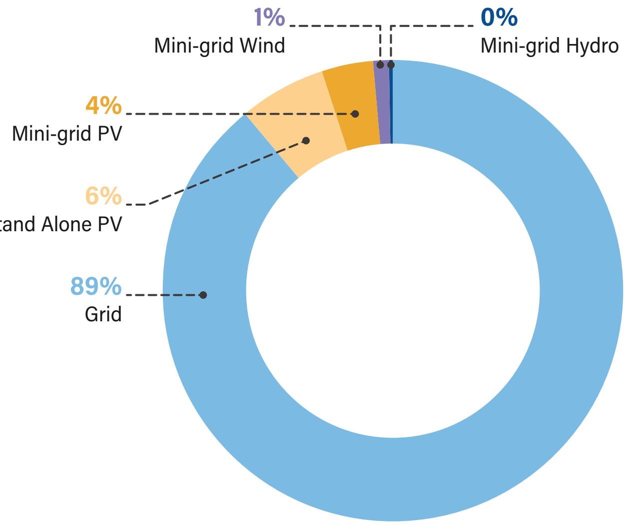


Note: Grid 2026 = Households for which the grid is the least-cost electrification solution in 2026; MG_Hydro 2026 = Households for which hydropower mini-grids are the least-cost solution in 2026; MG_PV 2026 = Households for which solar mini-grids are the least-cost solution in 2026; MG_Wind 2026 = Households for which wind-powered mini-grids are the least-cost solution in 2026; SA_PV 2026 = Households for which stand-alone photovoltaic (solar) is the least-cost solution in 2026; OnSSET = Open Source Spatial Electrification Tool.
Source: Authors.

Figure 12 shows the percentage of the population in Narok County that would be served by the different least-cost electrification technologies by 2026.

With regard to investment needs, Table 9 shows the investment costs required to deliver this scenario. At $599.3 million, the cost is significantly higher than those for Scenarios 1 and 2. This is attributed to forcing the model to depart from the least-cost solution for electrification and to utilise the grid when within a 2-km radius of it. Despite the reduced capacity, this scenario will cost more to implement than Scenario 2 by approximately $200 million. This can be attributed to the cost of grid expansion and providing a higher tier of access. Again, the grid is the only least-cost solution used in the intermediate year due to the initial grid densification and intensification process which must be done before it becomes too expensive to extend the grid further as compared with the off-grid technologies.

Figure 12 | **Percent of population in Narok County served by each type of least-cost electrification technology by 2026**



Note: PV = photovoltaic.
Source: Authors.

Table 8 | **Capacity of electrification technologies**

TECHNOLOGY	2024 (MW)	2026 (MW)	TOTAL
Grid	26.4	8.4	34.8
Stand-alone PV	0	9.2	9.2
Mini-grid PV	0	6.6	6.6
Mini-grid wind	0	1.9	1.9
Mini-grid hydro	0	0.062	0.062
Total			**52.8**

Note: MW = megawatt; PV = photovoltaic.
Source: Authors.

Table 9 | **Investment required in Scenario 3 in 2024 and 2026**

TECHNOLOGY	2024 (MILLIONS, $)	2026 (MILLIONS, $)
Grid	461.9	56.1
Stand-alone PV	0	44.5
Mini-grid PV	0	29.7
Mini-grid wind	0	6.6
Mini-grid hydro	0	0.40
Total	599.3	

Note: PV = photovoltaic.
Source: Authors.

Scenario 3 is our recommended electrification scenario for Narok County. While it may be more costly, the grid allows consumers to pay less for consumption, particularly compared with mini-grids where electricity can cost several times more. Further, grid consumers can acquire more appliances without the need for increased system capacity compared with solar home systems. Additionally, grid electrification is likely to be conducive for productive use of energy due to lower electricity costs and sufficient electricity supply.

Affordability analysis of proposed least-cost electrification solutions

We broke down Scenario 3 to the sub-county level to undertake a more granular affordability analysis and establish the affordability of the proposed technology choices per sub-county for the target year of achieving universal electrification (2026).

We performed an affordability analysis to determine the ability of households to pay based on a comparison between the levelised cost of electricity times the estimated consumption up to 2026 and the current average electricity expenditure per household, projected to 2026.

If the estimated expenditure using the least-cost electrification price was lower than the current expenditure per household, adjusted for inflation, we considered that electrification technology to be affordable.

Our affordability analysis was based on Scenario 3 since the county identified it as the scenario that balanced affordability and practicality of the infrastructure expansion. It is likely that the areas close to the grid will be electrified by the grid, and this scenario ensures that demand loads for the households would be met for both urban and rural areas. The results of this analysis can be seen in Table 10. Appendix F explains the full results and methodology used to carry out this analysis.

Table 10 shows that Narok South and Narok West would have a deficit between what they can afford to pay for electricity and what the electricity would cost them, while Narok North, Narok East, Transmara East, and Transmara West would be able to pay for the selected technology of choice (assuming current affordability remains constant).

It would therefore be necessary to source additional funding or innovative financing models to meet the deficit for the sub-counties that would be unable to pay for the proposed solutions.

Table 10 | **Affordability analysis**

SUB-COUNTY	AVERAGE AMOUNT EACH HOUSEHOLD WOULD BE WILLING TO SPEND (KES) ON ELECTRICITY PER MONTH (2026)	EXTRAPOLATED TOTAL ELECTRICITY EXPENDITURE PER YEAR IN 2026 (MILLIONS, KES)	MODELLED ELECTRICITY COST IN 2026 (MILLIONS, KES)	DEFICIT (MILLIONS, KES) (DIFFERENCE BETWEEN EXTRAPOLATED TOTAL EXPENDITURE AND MODELLED COST)
Narok North	906.7	733.0	610.762	122.3
Narok East	1,249.8	422.3	211.8	210.5
Narok South	876.1	551.6	674.6	–123.1
Narok West	563.7	293.6	372.0	–78.4
Transmara East	897.1	247.9	98.4	149.5
Transmara West	734.4	496.1	425.6	70.4
County totals	898.7	2,919.6	2,393.3	526.3

Notes: See Croome (2024) and MoE (2021) for more information. Willingness to pay is based on the current average electricity expenditure per household (from primary surveys), projected to 2026; Assumption: 1 US dollar = 120 Kenyan shillings (KES).
Source: Authors.

Integration of OnSSET modelling results in the Energy Access Explorer

We loaded the output files of these three scenarios—Domestic Electrification, Low Demand (Scenario 1); Domestic Electrification, High Demand (Scenario 2); and Domestic Electrification, High Demand, Grid Intensification (Scenario 3)—into EAE.

The outputs from OnSSET were in a GIS-ready format with each record representing information about a settlement cluster and the least-cost electrification technology that could best serve that settlement cluster by 2026. This made the outputs easy to integrate into EAE.

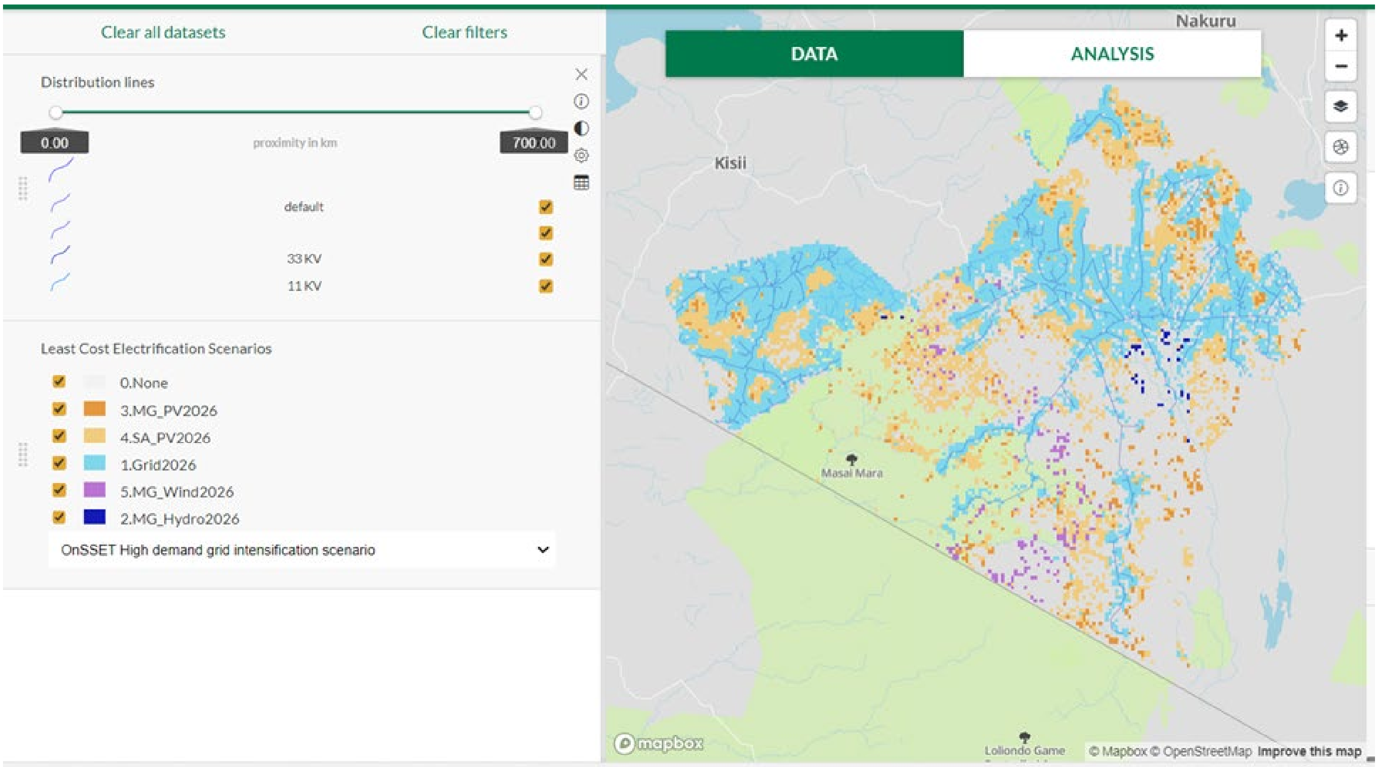
We assigned different colours representing the least-cost electrification technology choices identified to these settlement clusters to help distinguish those with similar technology.

Figure 13 illustrates the Scenario 3 results as visualised in EAE alongside the distribution lines in Narok County.

We then used these results from OnSSET to add further insights into the results of other multi-criteria analysis done using EAE.

For example, the results of the analysis provided in sub-section 'Electrification prioritisation analysis example using EAE for Narok County' are shown again in Figure 14 but with the Scenario 3 OnSSET results added to them.

Figure 13 | **Map showing the Scenario 3 OnSSET results loaded into the EAE**



Notes: In the map, light blue represents the settlement clusters that would be best electrified using grid extension and densification in 2026 (Grid2026) as the least-cost solution. You can see these locations are close to the grid, mostly within 2 km of the nearest distribution line. Dark brown illustrates settlements that would be best electrified using mini-grid solar (MG_PV2026), light brown depicts settlements that would be best electrified by solar stand-alone systems (SA_PV2026), purple shows settlements that would be best electrified by mini-grid wind (MG_Wind2026), and dark blue represents the settlements that would be best electrified by mini-grid hydro (MG_Hydro2026) in 2026. OnSSET = Open Source Spatial Electrification Tool; EAE = Energy Access Explorer.

Source: Authors.

As a reminder, this analysis considered the following input layers and filters:

- Population density
- Schools (proximity of 0–5 kilometres to the nearest school)
- Health care facilities (proximity of 0–5 kilometres to the nearest health facility)
- Distribution lines (greater than 2 km away)
- Global horizontal irradiation (greater than 2,000 kWh/m²/year)

The output map from EAE showed the areas that meet the above criteria in Narok County.

With the addition of the OnSSET layers to these results, we could further filter these areas to show those that met the selected criteria as well as which least-cost electrification solution would work for each settlement cluster.

In other words, we identified the settlements that could be best electrified using solar-based solutions (mini-grid solar and stand-alone solar home systems), or those that would have wind or hydro as their least-cost solutions, by further filtering the initial output from EAE.

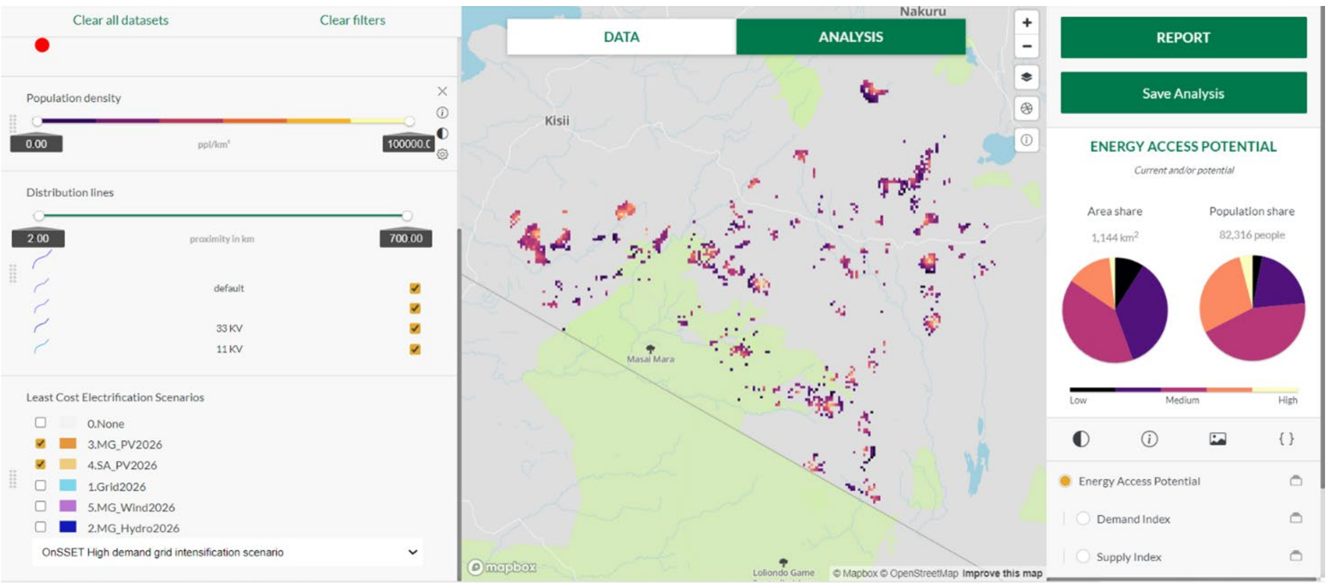
Figures 14–16 show the settlements that met the initial criteria from EAE distinguished by the least-cost electrification solution as identified from the OnSSET modelling.

As can be seen from these results, integrating outputs from the OnSSET cost-optimisation modelling into the multi-criteria analysis process from EAE generated additional insights that can be used to develop data-driven, location-specific solutions for achieving universal energy access.

Institutional electrification pathways and statistics

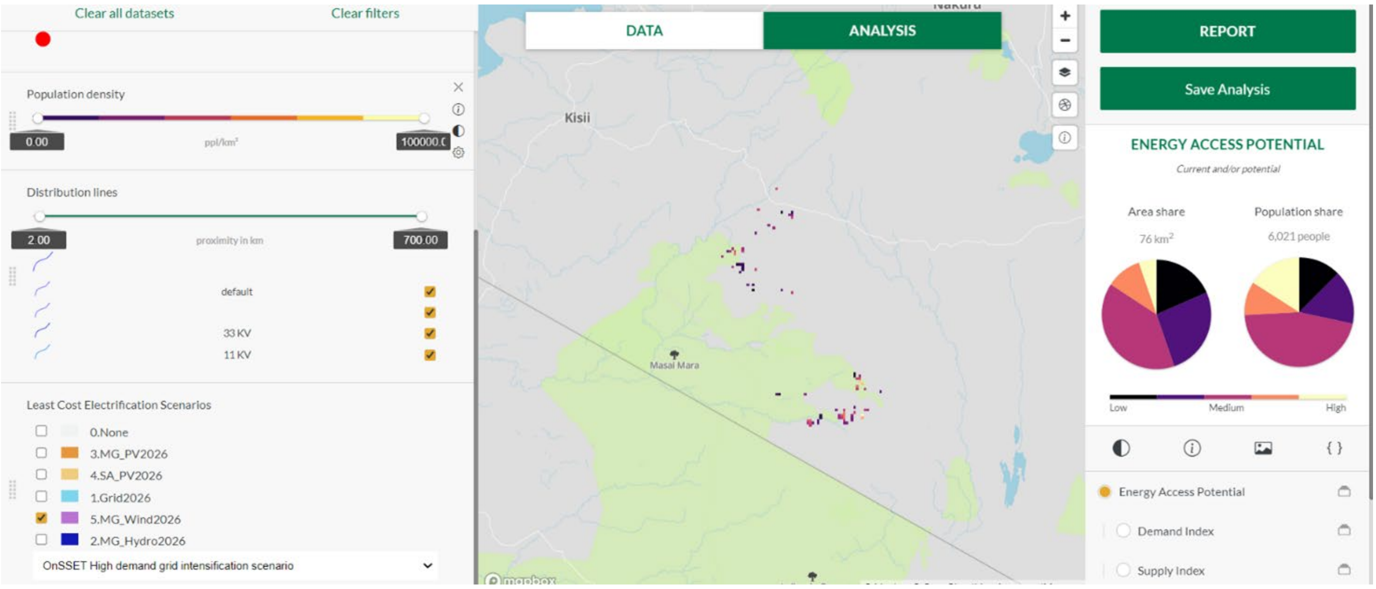
Institutional electrification was considered through grid densification. We undertook a proximity analysis to establish institutions that were 600 metres or more from distribution transformers. We assumed that these institutions were unelectrified (not connected to the grid). The unelectrified institutions were further extracted and overlaid with outputs from the County OnSSET High-Demand, Grid-Intensification scenario. Finally, using GIS proximity analysis, we assigned the institutions a least-cost electrification technology option based on the solution assigned to the nearest settlement cluster. The sections below present the results for electrification of health care facilities and schools.

Figure 14 | **Output results from the EAE showing the population settlements that have solar-based technology (mini-grid solar and stand-alone solar home systems) as the least-cost electrification option based on the selected criteria**



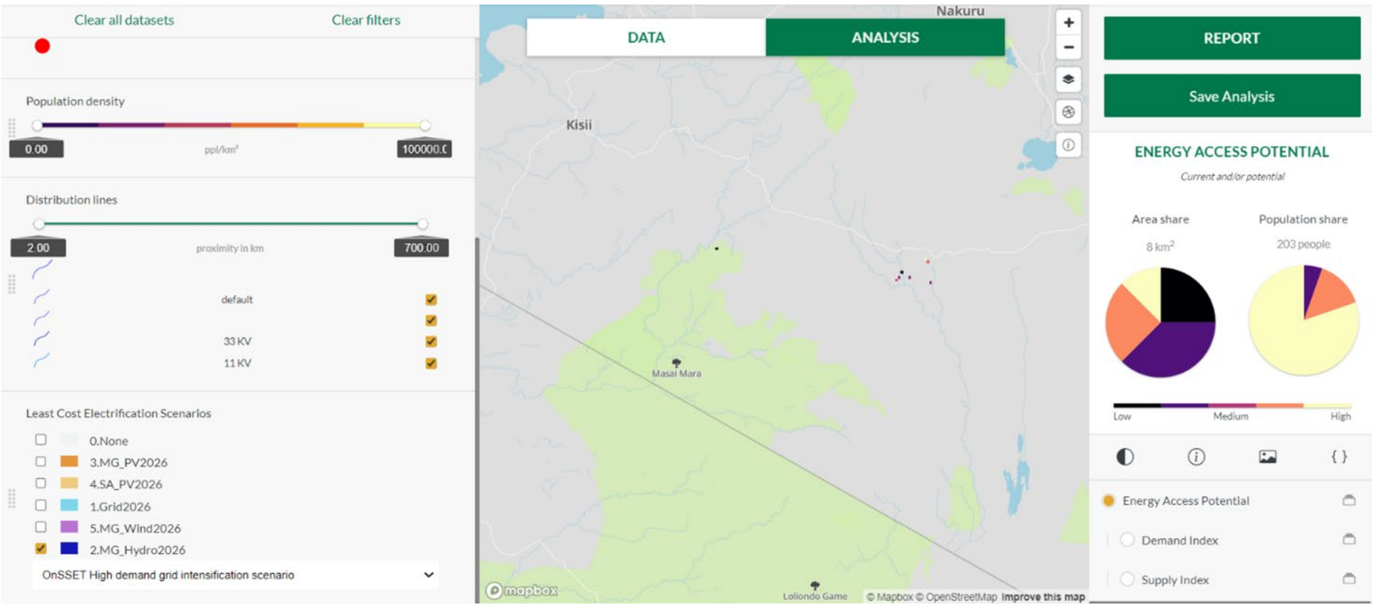
Note: EAE = Energy Access Explorer.
Source: Authors.

Figure 15 | **Output results from the EAE showing the population settlements that have wind-based technology (mini-grid wind) as the least-cost electrification option based on selected criteria**



Note: EAE = Energy Access Explorer.
Source: Authors.

Figure 16 | **Output results from the EAE showing the population settlements that have hydro-based technology (mini-grid hydro) as the least-cost electrification option based on selected criteria**



Note: EAE = Energy Access Explorer.
Source: Authors.

Health care facilities

Seventy-five health care facilities were flagged as unelectrified in the county (see Figure 17).

Table 11 summarises least-cost electrification technologies for health care facilities based on the findings from the GIS proximity analysis.

Table 11 shows that about half of the health care facilities (48 percent) can be electrified by the grid as the least-cost option. This is closely followed by stand-alone solar PV at 33 percent, indicating that many health care facilities are further from the grid than households.

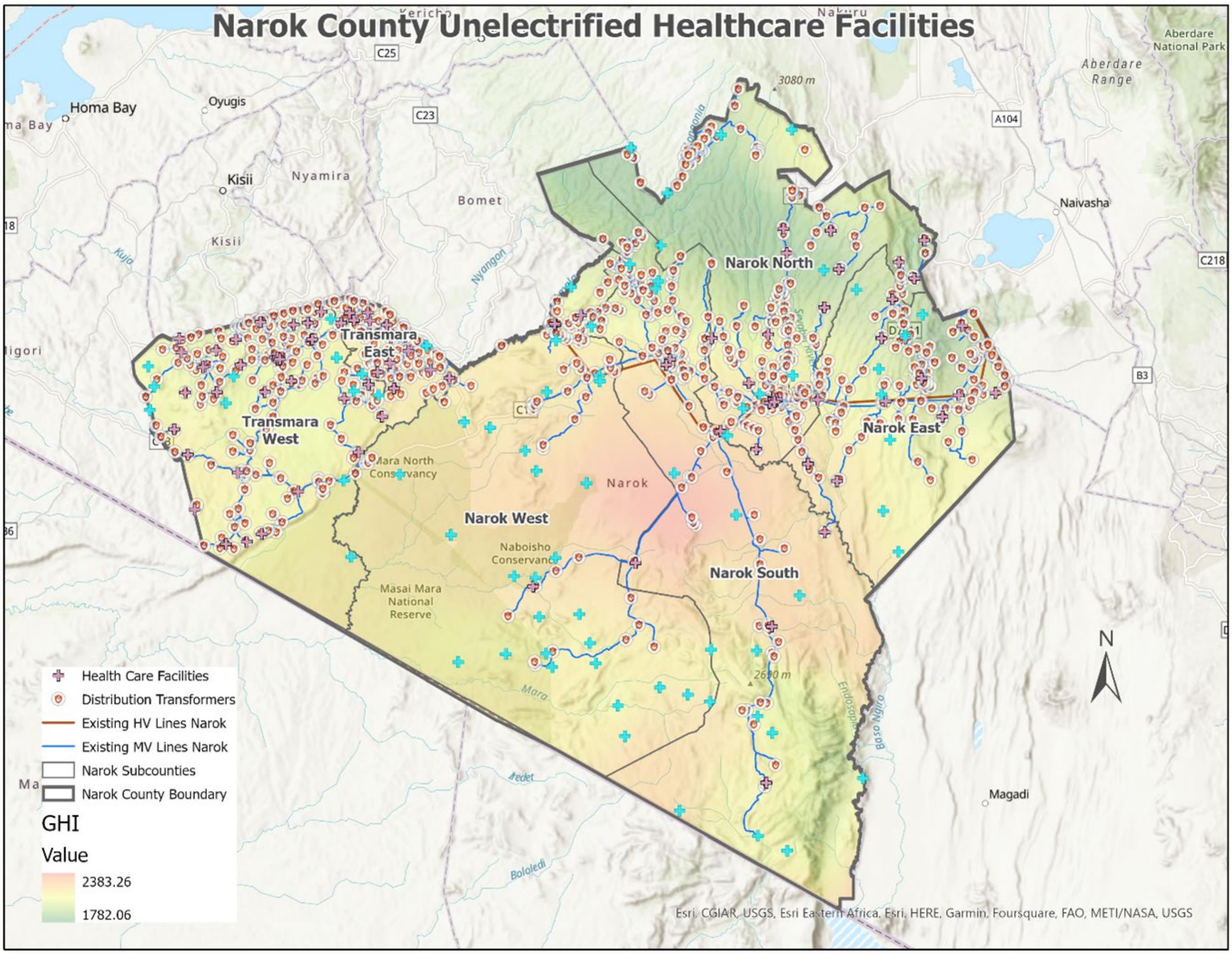
Schools

There are 265 unelectrified schools in the county (see Figure 18).

Table 12 summarises the electrification technologies that can be used to electrify schools.

Table 12 shows that slightly over half of the schools would be electrified using the grid (53 percent) followed by stand-alone solar PV (27 percent). This indicates that more schools than health care facilities are located close to the grid.

Figure 17 | **Map showing unelectrified health care facilities in Narok County as identified by GIS analysis**



Notes: The map assumes that a facility 600 metres or more from distribution transformers is not connected to the grid. Unelectrified health care facilities are shown in light blue. GIS = geographic information system; HV = high voltage; MV = medium voltage; GHI = global horizontal irradiation.

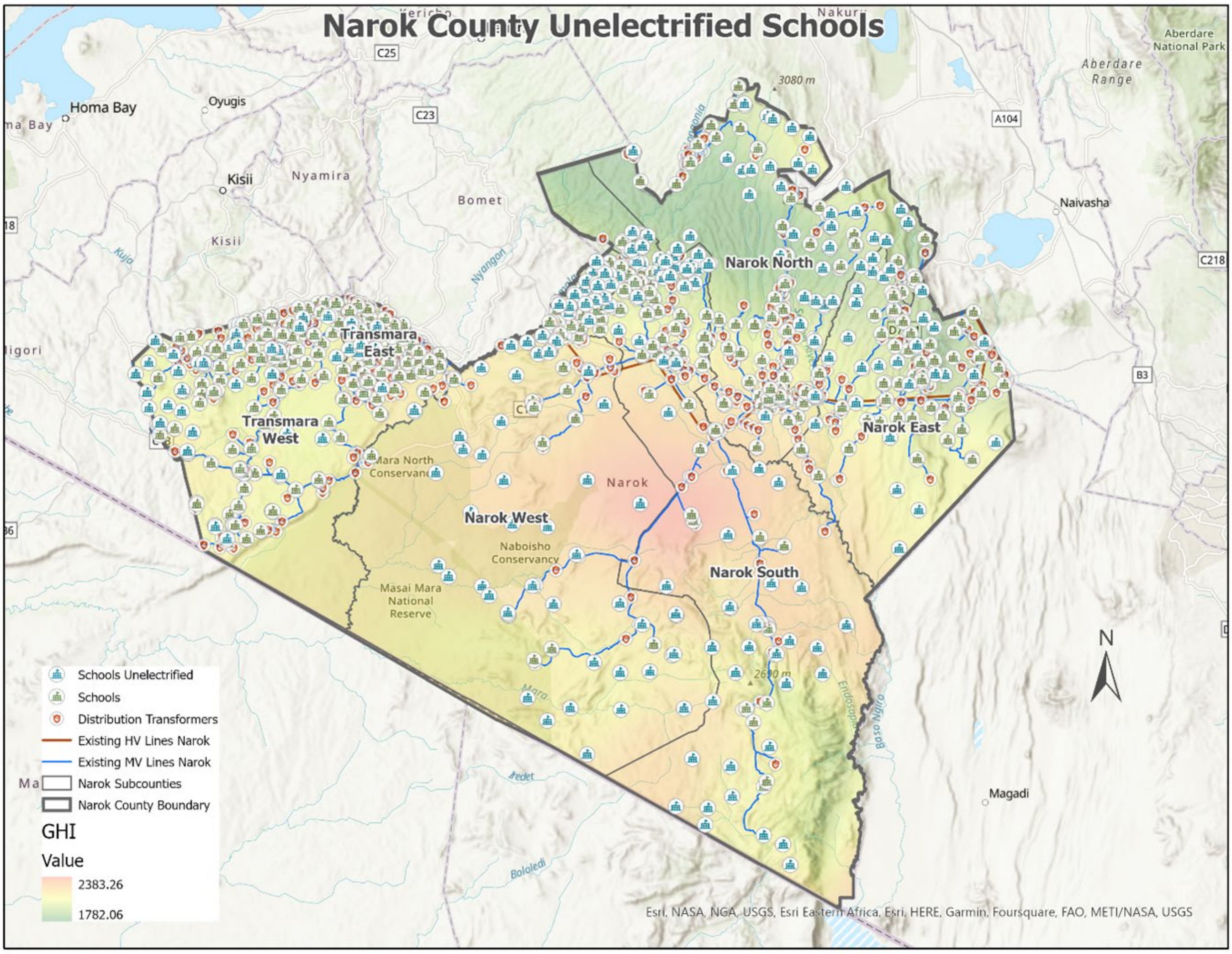
Source: Authors.

Table 11 | **Electrification technologies for unelectrified health care facilities**

SUB-COUNTY	GRID	STAND-ALONE PV	MINI-GRID PV	MINI-GRID HYDRO	MINI-GRID WIND	TOTALS
Narok North	7		1			**8**
Narok East	4	2	4			**10**
Narok South	7	6	2			**15**
Narok West	9	16	3		2	**30**
Transmara East						
Transmara West	9	1	2			**12**
Narok County Totals	**36**	**25**	**12**	**0**	**2**	**75**

Note: PV = photovoltaic.
Source: Authors.

Figure 18 | **Map showing unelectrified schools in Narok County as identified by GIS analysis**



Notes: This map assumes that a school 600 metres or more from distribution transformers is not connected to the grid. Unelectrified schools are shown in blue. GIS = geographic information system; HV = high voltage; MV = medium voltage; GHI = global horizontal irradiation.
Source: Authors.

Table 12 | **Electrification technologies for unelectrified schools**

SUB-COUNTY	GRID	STAND-ALONE PV	MINI-GRID PV	MINI-GRID HYDRO	MINI-GRID WIND	TOTALS
Narok North	28	11	13			**52**
Narok East	12	6	7	1		**26**
Narok South	33	16	11		2	**62**
Narok West	38	27	5		9	**79**
Transmara East	7	1				**8**
Transmara West	23	11	4			**38**
Narok County totals	**141**	**72**	**40**	**1**	**11**	**265**

Note: PV = photovoltaic.
Source: Authors.

Suggested electrification projects

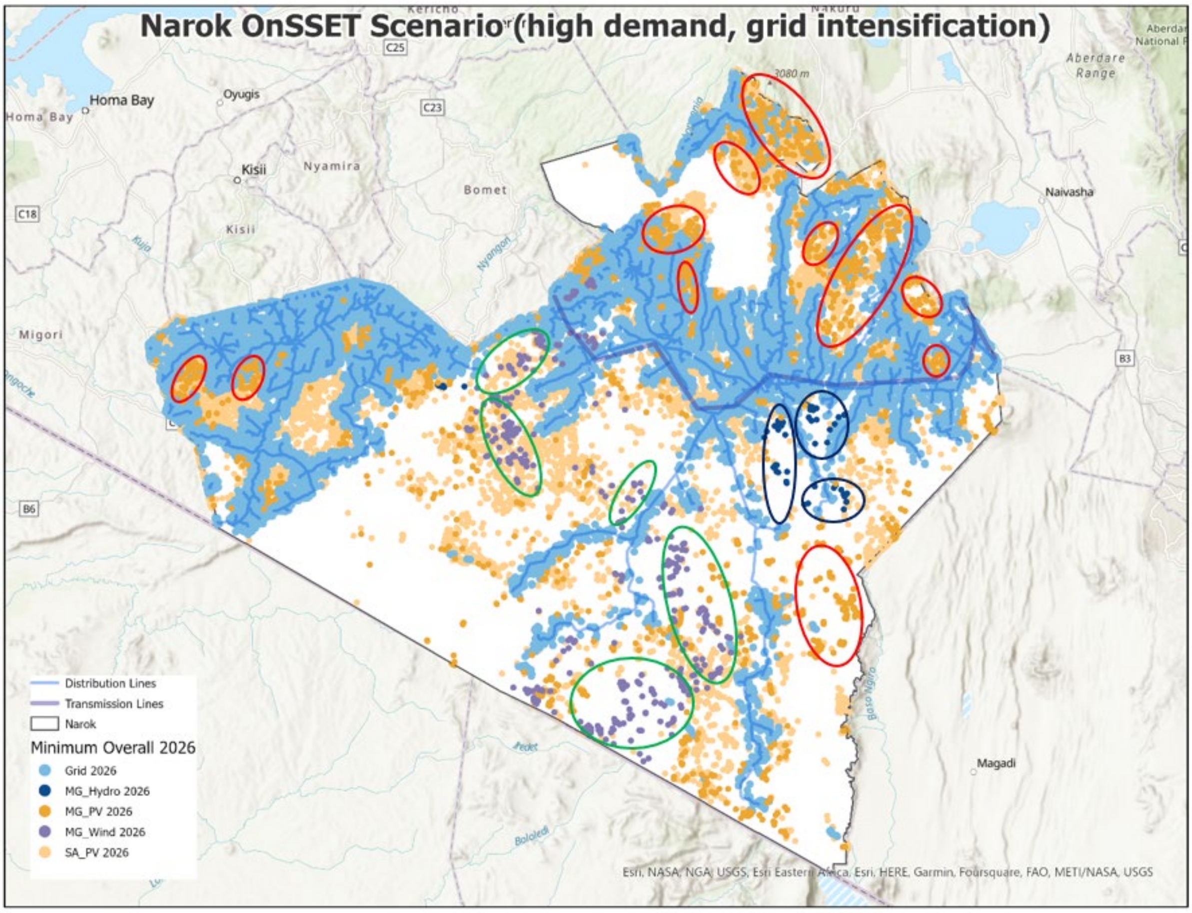
Based on the results of Scenario 3 (see section 'Scenario 3: Domestic Electrification, High Demand, Grid Intensification'), we analysed the output map to identify clusters of population settlements that have similar electrification technology solutions. We did this to identify potential areas for electrification projects using the most feasible and least-cost technology choice.

In Figure 19, clusters of population settlements that have the same recommended technology choice for electrification are shown in colour-coded circles. Potential areas for setting up solar mini-grids are circled in red, while those that have potential for setting up mini-grids using hydropower are circled in dark blue. Potential areas for setting up mini-grids using wind are circled in green.

The remaining areas are mainly those suitable for extending the grid and setting up stand-alone solar home systems which are uniformly distributed and coloured differently. Areas suitable for grid extension are mainly concentrated within 2 km of the grid while those suitable for stand-alone solar are randomly distributed. Most of the latter are much further away from the areas where the grid could be extended or where mini-grids could be set up.

More detailed feasibility and technical analysis would be needed to determine the exact design, capacity, and end users of the proposed power plants that would meet the needs of the unelectrified population and ensure universal access to electricity in Narok by 2026.

Figure 19 | **Map showing potential areas for setting up power plants using various least-cost technology options in Narok under Scenario 3**



Notes: Circles illustrate clusters of population settlements where the same proposed electrification solution is recommended. Solar mini-grid populations are circled in red; hydropower, dark blue; and wind, green. Grid 2026 = Households for which the grid is the least-cost electrification solution in 2026; MG_Hydro 2026 = Households for which hydropower mini-grids are the least-cost solution in 2026; MG_PV 2026 = Households for which solar mini-grids are the least-cost solution in 2026; MG_Wind 2026 = Households for which wind-powered mini-grids are the least-cost solution in 2026; SA_PV 2026 = Households for which stand-alone photovoltaic (solar) is the least-cost solution in 2026; OnSSET = Open Source Spatial Electrification Tool.

Source: Authors.

Conclusions

Centralised and granular GIS data play a key role in sub-national energy planning.

Narok's County Energy Plan development process made it clear that it is essential to take location into consideration when assessing current and projected energy demand and supply. It is necessary to combine a variety of demand- and supply-related spatial data (such as demographics and social and productive uses of energy as well as grid infrastructure and renewable energy potential) to carry out a multi-criteria analysis and identify priority areas for energy access interventions. This enables policymakers and renewable energy technology providers to assess the market and devise solutions that are relevant and appropriate to the right audiences and where energy investments are needed.

These datasets can play an important role for different stakeholders involved in energy access where each can combine different sets of data based on their preferences to identify the areas that meet their criteria. For instance, an energy planner in the Ministry of Energy might be interested in locating areas that have different characteristics than those that a clean-energy entrepreneur might want to locate. While the energy planner might be interested in locations where they can densify or extend the grid as a service and support the development of a long-term energy roadmap/plan, an energy entrepreneur might be interested only in areas where they are likely to make a profit from their energy solutions, such as areas where populations have the ability to pay or where the technologies are viable (i.e. the areas have high renewable energy potential or resources and are likely far from areas designated for grid expansion). The Energy Access Explorer provides the platform where all users can find the relevant data they need in one centralised location to carry out their own custom analyses. This publication describes how GIS datasets and analysis provide critical inputs for the energy planning process.

Adding least-cost and affordability modelling to energy planning further refines the energy planning process.

While the Energy Access Explorer identifies priority areas for energy access interventions (where to invest), OnSSET identifies what to invest in. The process of energy planning can be made more practical by identifying the most suitable and affordable energy technology solutions for all unelectrified settlements and social institutions such as schools and health facilities since the process of extending energy access can be very expensive. This publication demonstrates how least-cost electrification modelling can be done at a sub-national level with various scenarios including low and high energy demand, low and high population growth, and forced grid connection for areas close to the grid. One of the modelling outputs is the anticipated capacity (in MW) that would need to be installed to meet the demand by the targeted end year of the analysis as well as the technology investment cost required to make the scenarios a reality. Such datasets can be invaluable to energy planners since they can use them to seek needed funds and identify partners who can implement solutions to meet current and expected energy demand. Incorporating aspects of affordability provides energy planners with further insights with regard to the viability of the proposed supply solutions modelled for various geographies. All these outputs can greatly aid in decision-making and fundraising efforts in support of universal access to electricity.

Lessons learnt

Invest more in collecting, aggregating, and updating energy demand and supply datasets from various credible sources into one GIS data platform for ease of access and analysis. As is often the case with GIS analysis, the process of locating the relevant, accurate, and most up-to-date datasets for carrying out a multi-criteria analysis is often a daunting task, let alone the time needed to clean the data and convert them into the right formats, coordinate systems, and spatial resolution; heavy computational requirements; and GIS expertise required. EAE platform provides a solution for these challenges and can minimise the resource requirements associated with developing and maintaining a dynamic information system which can also support updates to integrated energy plans at the sub-national level.

Ensure energy planners are equipped with the skills needed to conduct a GIS data-driven approach to energy planning. As was evident during the CEP development process in Narok County, the county officials in the departments tasked with formulating the CEP expressed a deep appreciation for the role of GIS data and analytics in the whole process. Most were unfamiliar with working with GIS platforms and data and thus the project team conducted several capacity-strengthening sessions to equip them with the skills needed to use GIS mobile data collection tools and analyse energy demand and supply datasets using the Energy Access Explorer. This proved quite useful, and they were able to use their new skills to take part in the development of a quality energy plan. Thus, more capacity-building sessions on data-driven energy planning need to be done to ensure the sustainability of GIS platforms like EAE and should target a wide variety of stakeholders, including energy planners at the county and national levels, members of the private sector, and development finance institutions, among other stakeholders in the energy access space.

Familiarise other stakeholders at the county level with the GIS-based methodology we used to develop Narok's CEP. As mentioned previously, very few counties in Kenya have successfully completed the development of their County Energy Plans though doing so is required by law. This presents a unique opportunity to share the methodology we employed, especially with regard to applying GIS data, tools, and workflows to refine the process of sub-national energy planning by properly mapping and visualising the demand for energy and select localised solutions to meet this demand. In addition, the approaches, assumptions, and overall methodology for developing all 47 CEPs in Kenya should be standardised where possible since they will all feed into the Integrated National Energy Plan. Therefore, we recommend familiarising other counties which have not yet developed their CEPs with the approaches we used so they can apply them to their local contexts.

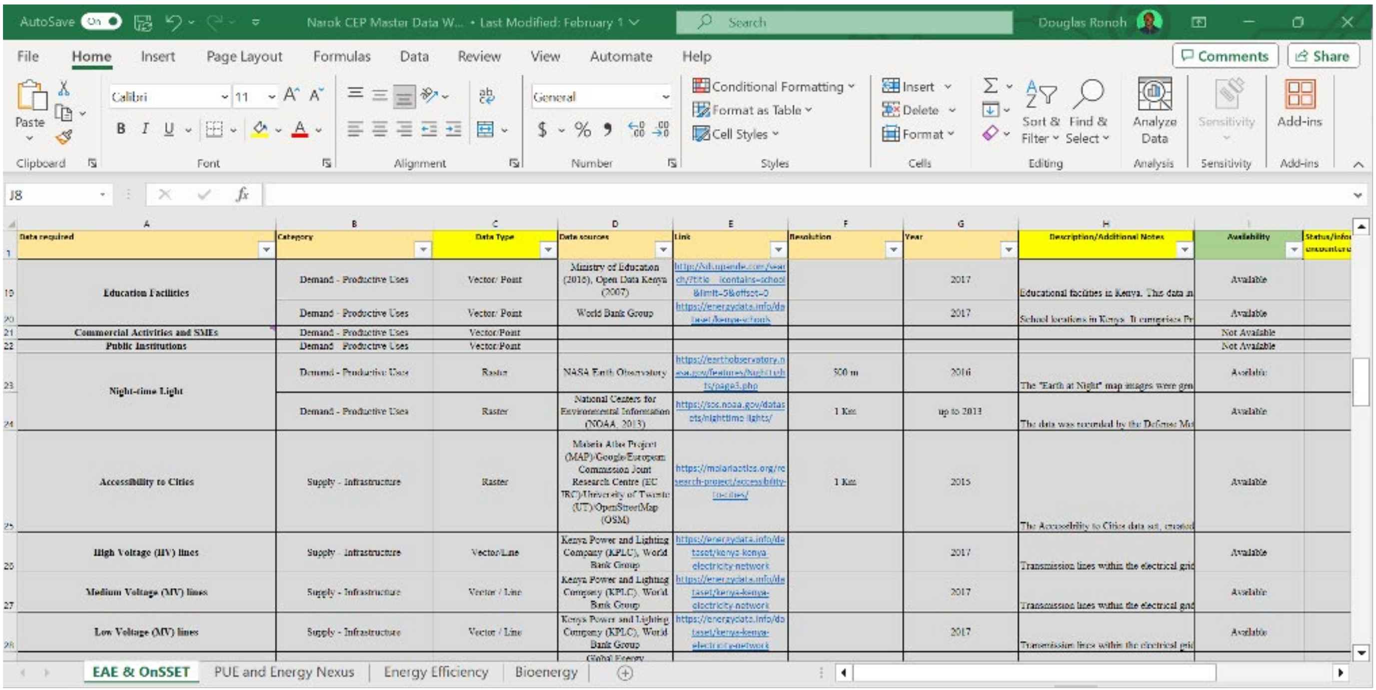
Targeted next steps

We recommend that the following next steps be taken by the county, project team, and other stakeholders:

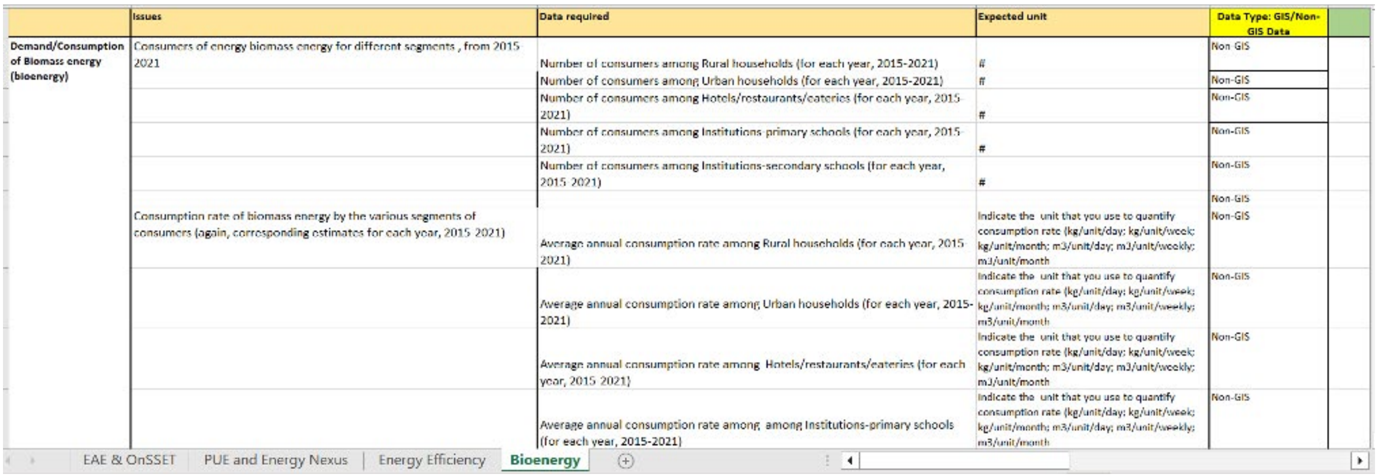
1. Incorporate the findings of this research into the Narok County Energy Plan to be used as a reference when designing and implementing electrification projects within the county.
2. Adopt and apply the methodology used in this publication when developing the County Energy Plans for other counties in Kenya that have not yet come up with their plans. Progress has been made on this front as this methodology has already been replicated in Makueni County. See Appendix H for more.
3. Use the findings from this publication to inform some of the projects in energy identified for implementation in the next five-year phase of the County Integrated Development Plan for Narok County. All counties prepare a CIDP to guide development over five-year periods. The CIDP contains information on development priorities that inform the annual budget process, particularly the preparation of the annual development plan, county fiscal strategy paper, and budget estimates.
4. Encourage target users such as development finance institutions, private sector energy entrepreneurs, and energy policymakers to apply EAE toolkit and analysis findings in this publication to implement energy projects that lead to increased adoption of renewable energy technologies, penetration of improved cookstoves, increased modern energy access, increased energy efficiency, increased productive use of energy, and sustainable use of biomass resources, ultimately contributing to reduced emissions.
5. Incorporate the findings from this CEP as an input into Kenya's Integrated National Energy Plan.

Appendix A. Narok CEP data wish list

Figure A-1 | **Narok County Energy Plan data wish list**



	Data required	Category	Data Type	Data sources	Link	Resolution	Year	Description/Additional Notes	Availability	Status/info encountered
19	Education Facilities	Demand - Productive Uses	Vector/ Point	Ministry of Education (2016), Open Data Kenya (2007)	http://sdi.upande.com/search/?title__icontains=school&limit=5&offset=0		2017	Educational facilities in Kenya. This data m	Available	
20		Demand - Productive Uses	Vector/ Point	World Bank Group	https://energydata.info/dataset/kenya-schools		2017	School locations in Kenya. It comprises Pr	Available	
21	Commercial Activities and SMEs	Demand - Productive Uses	Vector/Point						Not Available	
22	Public Institutions	Demand - Productive Uses	Vector/Point						Not Available	
23	Night-time Light	Demand - Productive Uses	Raster	NASA Earth Observatory	https://earthobservatory.nasa.gov/features/NightLights/page3.php	500 m	2016	The "Earth at Night" map images were gen	Available	
24		Demand - Productive Uses	Raster	National Centers for Environmental Information (NOAA, 2013)	https://sos.noaa.gov/datasets/nighttime-lights/	1 Km	up to 2013	The data was recorded by the Defense Me	Available	
25	Accessibility to Cities	Supply - Infrastructure	Raster	Malaria Atlas Project (MAP)/Google/European Commission Joint Research Centre (EC JRC)/University of Twente (UT)/OpenStreetMap (OSM)	https://malariaatlas.org/research-project/accessibility-to-cities/	1 Km	2015	The Accessibility to Cities data set, created	Available	
26	High Voltage (HV) lines	Supply - Infrastructure	Vector/Line	Kenya Power and Lighting Company (KPLC), World Bank Group	https://energydata.info/dataset/kenya-kenya-electricity-network		2017	Transmission lines within the electrical grid	Available	
27	Medium Voltage (MV) lines	Supply - Infrastructure	Vector / Line	Kenya Power and Lighting Company (KPLC), World Bank Group	https://energydata.info/dataset/kenya-kenya-electricity-network		2017	Transmission lines within the electrical grid	Available	
28	Low Voltage (MV) lines	Supply - Infrastructure	Vector / Line	Kenya Power and Lighting Company (KPLC), World Bank Group	https://energydata.info/dataset/kenya-kenya-electricity-network		2017	Transmission lines within the electrical grid	Available	

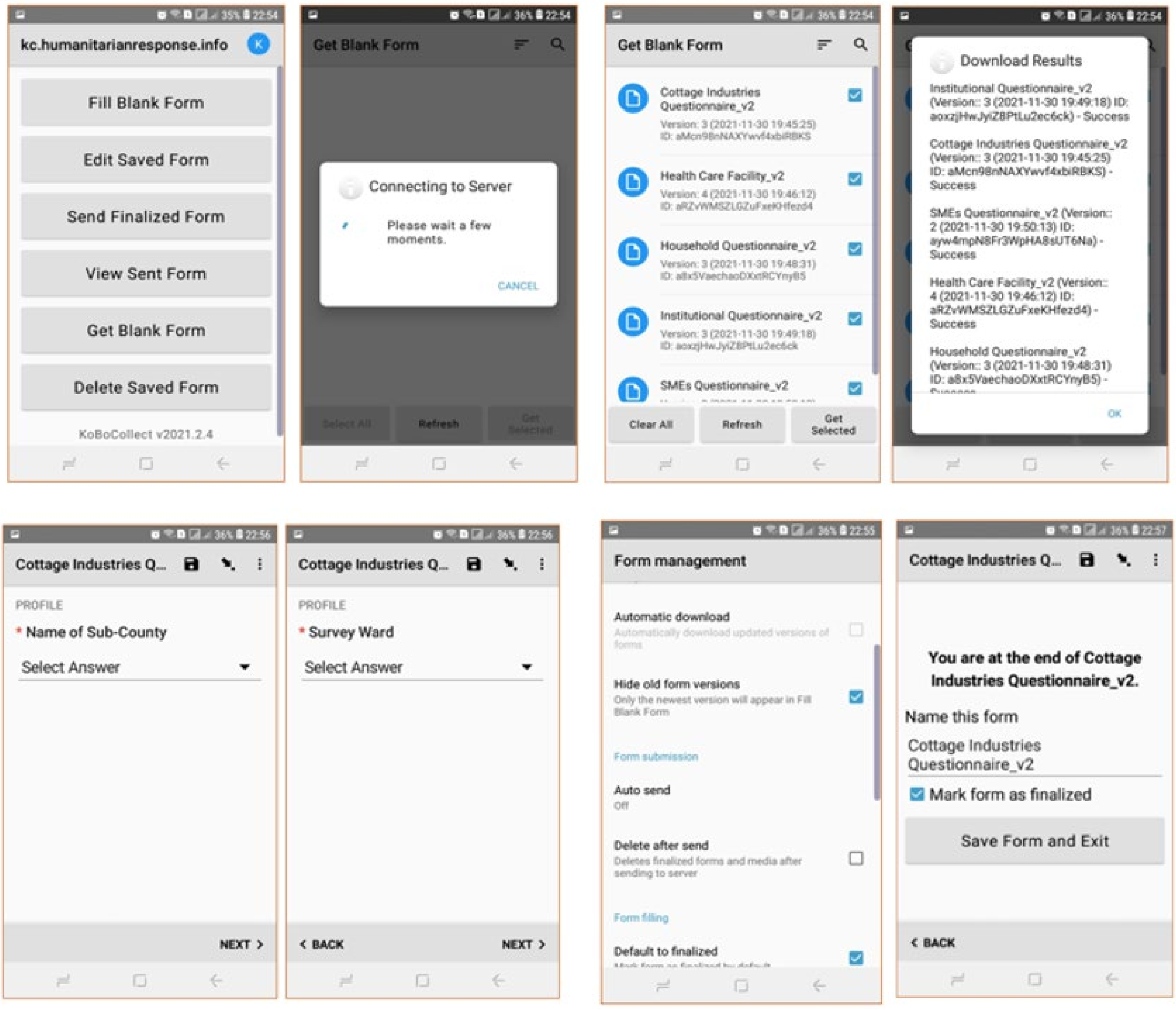


	Issues	Data required	Expected unit	Data Type: GIS/Non-GIS Data
Demand/Consumption of Biomass energy (bioenergy)	Consumers of energy biomass energy for different segments , from 2015 2021	Number of consumers among Rural households (for each year, 2015-2021)	#	Non GIS
		Number of consumers among Urban households (for each year, 2015-2021)	#	Non-GIS
		Number of consumers among Hotels/restaurants/cateries (for each year, 2015 2021)	#	Non-GIS
		Number of consumers among Institutions primary schools (for each year, 2015 2021)	#	Non-GIS
		Number of consumers among Institutions-secondary schools (for each year, 2015 2021)	#	Non-GIS
				Non-GIS
	Consumption rate of biomass energy by the various segments of consumers (again, corresponding estimates for each year, 2015 2021)	Average annual consumption rate among Rural households (for each year, 2015 2021)	Indicate the unit that you use to quantify consumption rate (kg/unit/day; kg/unit/week; kg/unit/month; m3/unit/day; m3/unit/weekly; m3/unit/month	Non-GIS
		Average annual consumption rate among Urban households (for each year, 2015-2021)	Indicate the unit that you use to quantify consumption rate (kg/unit/day; kg/unit/week; kg/unit/month; m3/unit/day; m3/unit/weekly; m3/unit/month	Non-GIS
		Average annual consumption rate among Hotels/restaurants/eateries (for each year, 2015 2021)	Indicate the unit that you use to quantify consumption rate (kg/unit/day; kg/unit/week; kg/unit/month; m3/unit/day; m3/unit/weekly; m3/unit/month	Non-GIS
		Average annual consumption rate among among Institutions-primary schools (for each year, 2015-2021)	Indicate the unit that you use to quantify consumption rate (kg/unit/day; kg/unit/week; kg/unit/month; m3/unit/day; m3/unit/weekly; m3/unit/month	Non-GIS

Source: Authors.

Appendix B. User interface of the KoboCollect application

Figure B-1 | **KoboCollect application user interface**



Source: Authors.

Appendix C. EAE functionalities (front end and back end)

How can the Energy Access Explorer help energy planning agencies?

EAE identifies areas where electrification and socio-economic development can be linked to meet the needs of the poor. It can complement the cost optimisation planning tools that energy planners already use, providing a bottom-up representation of electricity affordability and demand.

Using the tool, planning agencies and energy ministries can identify areas where there are households, schools, health clinics, and other facilities with no connection to the grid. Supplying electricity to these areas is essential to advancing socioeconomic development, improving quality of life, upgrading basic health and education services, and boosting gender equality.

EAE architecture

EAE is a dynamic geographic information system with an open-source, adaptable web architecture. Beyond its visualisation and analytical capabilities, EAE's unique back-end infrastructure provides the following:

- Automated data processing to minimise resource requirements when it comes to harmonising and integrating new data
- A dynamic database and efficient data storage to optimise data transactions and configurations
- Customised content management system which allows admin users to better process, store, manage, and update EAE in a cost-effective manner
- A modular application programming interface that connects the back end of the application with the front end and enables users to generate rapid, high-resolution visualisations and prioritisation analysis on the fly
- A variety of baseline maps which include the names of places and satellite imagery, among other features

Tables C-1 and C-2 further outline EAE's functionalities.

Front end

EAE's front end, shown in Figure C-1, provides the user interface for loading data, applying queries and filters, and performing multi-criteria analysis, among other functions listed above.

Back end

The back-end architecture of EAE—for data storage, management, processing, and updating—is shown in Figure C-2.

Table C-1 | **Front-end functionalities of the Energy Access Explorer**

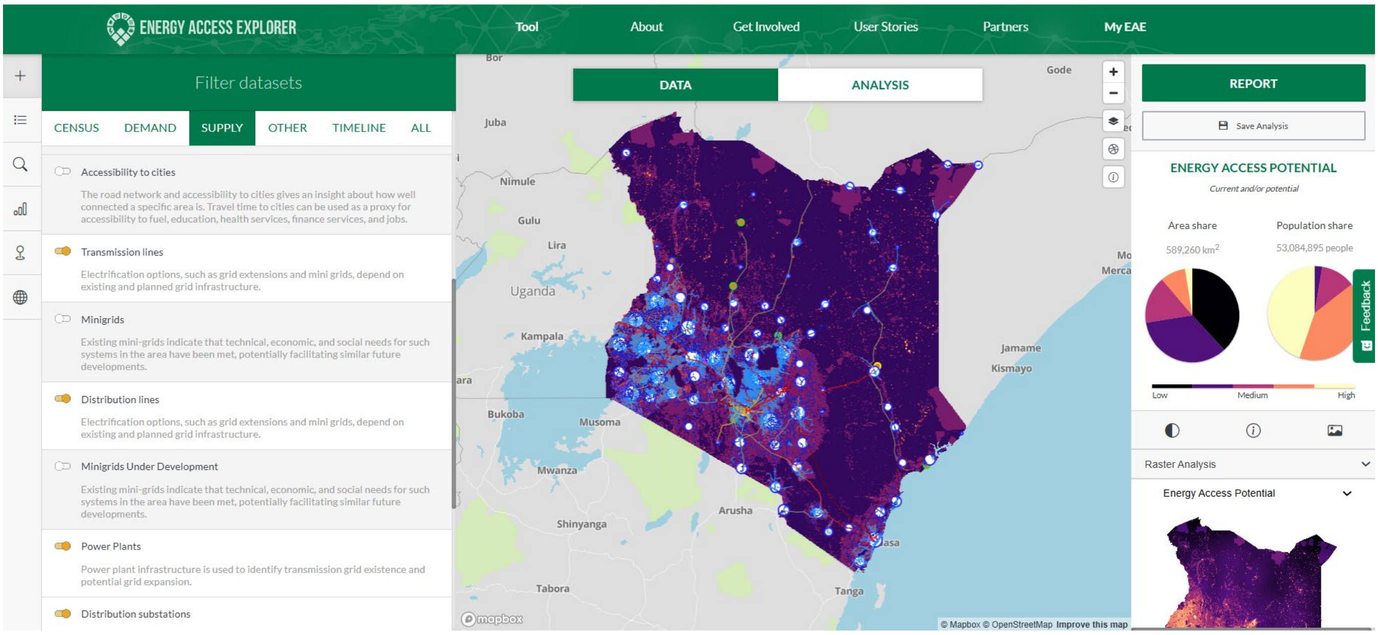
FUNCTIONALITY	STATUS
Select and visualise geospatial data	Launched
User-friendly interface	Launched
Overlay data	Launched
On-the-fly high-resolution, multi-criteria decision analysis that provides four 'heat maps'/analytical outputs; these include and prioritise areas of interest as defined by users' custom criteria and selections	Launched
Apply queries, filters, and buffers	Launched
High-resolution, multi-criteria analysis (1 km^2)	Launched
List high-priority areas	Launched
View on desktop and mobile phone internet browsers	Launched
Customisable base maps (e.g. satellite, light, dark plus labels)	Launched
View in a public version	Launched
View in a password-protected version	Staging, testing, training environments
View in an offline version	Staging, testing, training environments

Table C-1 | Front-end functionalities of the Energy Access Explorer (cont.)

FUNCTIONALITY	STATUS
Zoom-in feature to select smaller administrative divisions and see custom versions of the app (including input data and outputs of the analysis) for these areas	Launched
Search for and summarise the top 20 locations in terms of the select indicators or the analytical outputs (e.g. show the 20 locations with the highest wind speed or the 20 locations with the highest energy access potential)	Launched
Develop custom summary reports and dashboards	Launched
Search for coordinates or areas of interest	Launched
Save analysis in MyEAE and download analysis reports and presentations	Launched
Visualise temporal data to track progress as well as model energy-transition scenarios such as solar/wind supply regions	Launched

Note: km² = square kilometre.
Source: Authors.

Figure C-1 | Energy Access Explorer's front-end user interface



Source: Authors.

Table C-2 | Back-end functionalities of the Energy Access Explorer

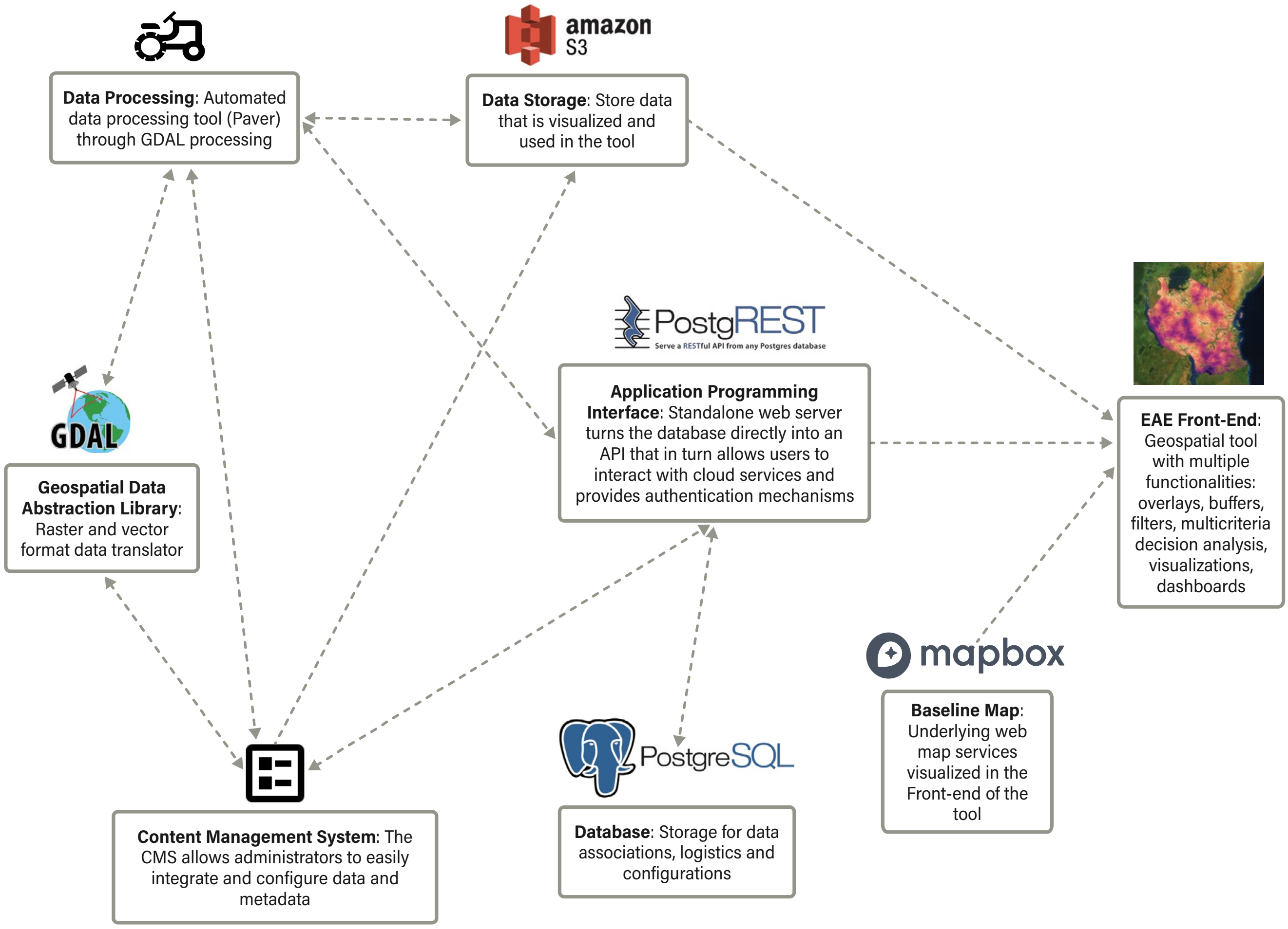
FUNCTIONALITY	STATUS
User-friendly interface	Launched
Ability to add data in different resolutions, types, formats	Launched
Ability to add metadata	Launched
Modify visualisations/symbols	Launched
Categorise data and change the order they appear in the front end	Launched
Automated data processing	Launched

Table C-2 | **Back-end functionalities of the Energy Access Explorer (cont.)**

FUNCTIONALITY	STATUS
Enable searchability of data	Launched
Data sorting	Launched
Dynamic database	Launched
Efficient data storage	Launched
Last update feature	Launched
Staging site for testing and training	Launched
Link with Amazon Web Services	Launched
Link to other cloud services	Launched (admin can choose)
A modular application programming interface that connects back end and front end	Launched
Add new multi-criteria analysis defined by administrators	Launched
Automated data pre-processing	Launched

Source: Authors.

Figure C-2 | **Energy Access Explorer's back-end architecture**



Note: GDAL = Geospatial Data Abstraction Library; CMS = content management system; API = application programming interface.
Source: Authors.

Appendix D. OnSSET Python and specs-file input parameters

Python input parameters

The values for the parameters in Table D-1, such as the default values, were already in the OnSSET Python files. However, we updated some of these with new Narok County–specific values obtained from various published sources (Pueyo et al. 2024; Moksnes et al. 2020).

Specs-file input parameters

The values in Table D-2 were entered in an .xlsx file used as an input in the model. Note that some of the inputs changed in the sub-counties' analysis to represent the specific values for each sub-county.

Table D-1 | **OnSSET Python and specs-file input parameters**

PARAMETER	DESCRIPTION	UNIT	VALUE USED
BASE_YEAR	The base year of the analysis; note that this parameter is highly related to the input GIS data, which should, if possible, be calibrated toward the base year (e.g. the population distribution map should represent the base year values)	Year	2022
END_YEAR	The final year of the analysis	Year	2026
Scenario	The input value here represents the annual electricity consumption per household that is expected to be achieved by the end year	kWh/HH/year	Tier 1 for rural HHs Tier 4 for urban HHs
sa_pv_capital_cost	The capital cost (per capacity unit) of a stand-alone PV module	$/kW	3,321
mg_diesel_capital_cost	The capital cost (per capacity unit) of a mini-grid diesel generator	$/kW	721
mg_pv_capital_cost	The capital cost (per capacity unit) of a mini-grid PV system	$/kW	3,051
mg_wind_capital_cost	The capital cost (per capacity unit) of a mini-grid wind-powered system	$/kW	2,538.8
mg_hydro_capital_cost	The capital cost (per capacity unit) of a mini-grid hydropower system	$/kW	2,589
existing_grid_cost_ratio	Incremental cost increase to extend the grid from an electrified settlement to an unelectrified one; default value set at 10%	Ratio	
discount_rate	The discount rate applied to different technology configuration choices throughout the period of analysis	Ratio	0.08

Notes: OnSSET = Open Source Spatial Electrification Tool; GIS = geographic information system; kWh/HH/year = kilowatt-hour per household per year; kW = kilowatt; PV = photovoltaic.
Sources: Pueyo et al. 2024; Moksnes et al. 2020.

Table D-2 | **Specs-file input parameters (demographics)**

PARAMETER	DESCRIPTION	UNIT	VALUE USED
County	The name of the study area	N/A	Narok
Pop2022	The population of the selected area in the base year	People	1,276,327
UrbanRatio2022	The ratio of urban population in the selected area in the base year	Ratio	0.07
Pop2026	The projected population[a]	People	1,550,829
UrbanRatio2026	The ratio of urban population in the selected area in the end year	Ratio	0.1
NumPeoplePerHHRural	Number of people per household in rural areas	People	5.6
NumPeoplePerHHUrban	Number of people per household in urban areas	People	4
GridCapacityInvestmentCost	The investment required per unit of additional capacity for the national grid; this is an average value based on the mix of technologies used in the country	$/kW	2,772
GridLosses	This value represents the geographical area's average technical losses on transmission and distribution	Ratio	0.1

Table D-2 | **Specs-file input parameters (demographics) (cont.)**

PARAMETER	DESCRIPTION	UNIT	VALUE USED
BaseToPeak	This value represents the ratio between the base and peak load in the selected geographical area; it is used for sizing the necessary capacity to be installed per settlement to cover the respective demand	Ratio	0.85
ExistingGridCostRatio	Incremental cost increase to extend the grid from an electrified settlement to an unelectrified one; default value set at 10%	Ratio	0.1
MaxGridExtensionDist	The input parameter sets the maximum distance for which the grid can be extended to electrify a settlement due to techno-economic considerations; the default value in the model is 50 km	km	50
ElecActual	The electrification rate in the selected area in the base year (i.e. ratio of population that is electrified)	Ratio	0.224
MaxGridDist	The input parameter sets the maximum distance from the existing or planned grid network under which the model will consider a settlement as electrified	km	1
MaxRoadDist	The input parameter sets the maximum distance from the existing or planned road network under which the model will consider a settlement as electrified	km	0.5
PopCutOffRoundOne/ PopCutOffRoundTwo	These input parameters set the minimum population value under which the model will consider a settlement as electrified; if the value in round one is not satisfactory, the programme will move on to round two (round two must have a higher value than round one)	People	5,000/10,000
UrbanCutOff	This input parameter sets the minimum population value under which the model will consider a settlement as urban	People	100

Note: N/A = not applicable; kW = kilowatt; km = kilometre.
Source: KNBS 2016.

Appendix E. OnSSET scenario combinations

Table E-1 | **OnSSET scenario combinations**

SCENARIO PARAMETERS	CHOICE	EXPLANATION OF CHOICE OPTIONS
Population growth	0, 1	Expected population in the geographic area by the end year of the analysis; 0: low/ expected population growth (3.3%), 1: high population growth (4%)
Target_electricity_consumption_level	0, 1, 2	0: low electricity demand target (Tier 1[a] for rural, Tier 4 for urban); 1: high electricity demand target (Tier 2 for rural, Tier 5 for urban); 2: custom residential demand target layer (from GIS)
Electrification_target_5_years	0, 1	0: low electrification target in the intermediate year (e.g. 35%); 1: high electrification target in the intermediate year (e.g. 60%)
Grid_electricity_generation_cost	0, 1	0: low generating cost for the grid (e.g. 0.047 $/kWh); 1: high generating cost for the grid (e.g. 0.059 $/kWh)
PV_cost_adjust	0, 1, 2	0: PV capacity cost as defined by the user; 1: PV capacity cost reduced by 25%; 2: PV capacity cost increased by 25%
Productive_uses_demand	0, 1	0: not including productive uses of electricity; 1: including productive uses of electricity
Prioritisation_algorithm	0, 1, 2	0: least-cost prioritisation; 1: forced grid within 1 km; 2: forced grid within 2 km

Note: [a] Tiers of demand are used to approximate demand in rural and urban areas and not to define electrification solutions. See Table 2 for more. OnSSET = Open Source Spatial Electrification Tool; GIS = geographic information system; kWh = kilowatt-hour; PV = photovoltaic; km = kilometre.
Source: Authors.

Appendix F. Affordability analysis, full results

Table F-1 illustrates the findings of the affordability analysis.

Table F-1 | **Full results of the affordability analysis**

SUB-COUNTY	AVERAGE AMOUNT PER HH SPENT (KES) ON ELECTRICITY PER MONTH (A)	FUTURE VALUE OF AVERAGE AMOUNT PER HH SPENT (KES) ON ELECTRICITY PER MONTH IN 2026 (B)	TOTAL HH (2019 CENSUS) - (C)	TOTAL HH (2026) - (D) =C*1.67% ANNUAL GROWTH RATE	EXTRAPOLATED TOTAL ELECTRICITY EXPENDITURE PER YEAR IN 2026 (MILLIONS, KES) - (E) = B*D*12	LCOE * ELECTRICITY CONSUMPTION (MILLIONS, KES) ON SCENARIO TO ACHIEVE UNIVERSAL ENERGY ACCESS IN 2026 - (F)	DEFICIT (MILLIONS, KES) - (G) = E - F
Narok North	**563**	**906.7**	**59,996**	**67,371**	733.0	610.762	122.3
Narok East	**776**	**1,249.8**	**25,078**	**28,161**	422.3	211.8	210.5
Narok South	**544**	**876.1**	**46,723**	**52,466**	551.6	674.6	–123.1
Narok West	**350**	**563.7**	**38,658**	**43,410**	293.6	372.0	–78.4
Trans Mara East	**557**	**897.1**	**20,506**	**23,027**	247.9	98.4	149.5
Trans Mara West	**456**	**734.4**	**50,132**	**56,294**	496.1	425.6	70.4
County totals	**558**	**898.7**	**241,093**	**270,729**	**2,919.6**	2,393.3	526.3

Notes: HH = household; LCOE = levelised cost of energy. LCOE is the final cost of electricity per kilowatt-hour required for the overall system to break even over the project lifetime for the selected least-cost technology choice.

Electricity consumption = Residential demand tier of choice * Population projected for 2026

- Residential demand tier: Consumption per capita per year for a certain efficiency level (Tier 1 for rural and Tier 4 for urban) (see Table 2 on residential demand tiers)
- Population projected for 2026: Assuming a high population growth rate of 4 percent per year since the released 2019 census result per sub-county

Assumption: 1 US dollar = 120 Kenyan shillings.

Household growth rate = 1.67 percent per annum (MoE 2021; KPLC 2017c).

We arrived at the extrapolated total electricity expenditure by multiplying the expected number of households in 2026 (projected at a growth rate of 1.67 percent) and the expected average electricity expenditure per household in 2026 obtained from primary data collection in 2021 (after factoring in the future value of money of the 2021 electricity expenditure in 2026). We used the model's discount rate (10 percent) to obtain the value of money in 2026. We estimated the average amount spent on electricity per household in 2026 based on the future value (KPLC 2017b) of the amount spent per household in 2021 as per the primary household surveys, assuming a 10 percent annual increment.

We then calculated affordability by looking at the LCOE for the least-cost electrification solutions proposed and multiplying that by the proposed tiers of access that urban versus rural households are projected to consume annually in terms of total units per capita. This generated how much households would spend on electricity per year if supplied with the technologies proposed. We then compared this with how much they are currently spending on electricity or the energy for lighting solutions (from the primary survey results) that they are currently using projected per year, factoring in the future value of this expenditure in 2026. The difference is the level of affordability (i.e. what households are currently comfortable spending on electricity versus what they would be required to spend if supplied with the least-cost electrification solution).

Source: Authors.

Appendix G. Household questionnaire (primary data collection)

Table G-1 shows the questionnaire used for primary data collection for households.

Table G-1 | **Household survey protocol**

#	VARIABLE	CHOICES	UNIT
A	PROFILE		
1	Name of sub-county		Name
2	Survey ward		Name
3	Survey location		Name
4	Survey sub-location		Name
5	Set GPS coordinates** GCS WGS 84 Datum: d.ddddo		
I	Latitude		d.dddd0
II	Longitude		d.dddd0
III	Indicate if the household is URBAN or RURAL	Urban	Assign one choice
		Rural	
6	Enter date of the survey		Date
7	Enumerator ID		ID
B	HOUSEHOLD CHARACTERISTICS		
8	Household ID		
9	Respondent's name		
10	Respondent's phone number		
11	Gender of the respondent: MALE or FEMALE		Assign one choice
12	Is the respondent the head of the household? YES or NO		Assign one choice
	If they responded NO to question 12, THEN answers must be provided to questions 13 and 14.		
13	What is the gender of the household head? MALE or FEMALE		Assign one choice
14	Age of the respondent: Surveyor to prompt and assign the correct age bracket.	18–25	Assign one choice
		26–35	
		36–45	
		Over 45	
15	Marital status of the respondent: Surveyor to prompt and assign the correct status.	Married	Assign one choice
		Single	
		Separated or divorced	
		Widowed	
16	How many members of this household are younger than 5?		#
17	Highest education level the household head has attained: Surveyor to prompt and assign the correct level.	Primary	Assign one choice
		Secondary	
		College	
		University	
18	Is the respondent the owner or a tenant of their home?	Homeowner	Assign one choice
		Tenant	
C	ECONOMIC STATUS		

Table G-1 | **Household survey protocol (cont.)**

#	VARIABLE	CHOICES	UNIT
19	Is the family sedentary (settled) OR nomadic?	Sedentary (settled)	Assign one choice
		Nomadic	
20	What is the size of the family (number of household members)? The surveyor must make it clear that it is only the number of family members who depend on the same budget for their daily livelihood who are included as household members. Those who are married are taken to have their own families.		#
21	What economic activity does the respondent engage in consistently? Surveyor to prompt and assign the correct choice.	Employed	Assign one choice
		Crop farming	
		Casual labour	
		Fish farming	
		Livestock keeping	
		Trade/Business	
		Beekeeping	
		None	
		Other (specify)	
22	What is the household's total monthly income (including money from any source)? The surveyor is to pool all income generated monthly from all income-generating activities by the household, and also from all members considered to belong to the household (see definition above for those not considered household members).	2,000–5,000	Assign one choice
		5,001–10,000	
		10,001–20,000	
		20,001–30,000	
		30,001–40,000	
		40,001–50,000	
		Above 50,000	
D	ACCESS TO LAND, CROPPING, AND FEEDSTOCK FOR BIO-ENERGY		
23	What is the quantity of land (in acres) that the household has access to?		Acre
	If the answer to question 23 is more than zero acres, THEN answers must be provided for questions 24–29.		
24	Provide an estimate of the land size (acres) under maize crops.		Acre
25	Provide an estimate of the land size (acres) under wheat crops.		Acre
26	When the household members have harvested the maize crop, do they collect the residues (maize stovers and maize cobs) for any use?	Yes	Assign one choice
		No	
27	What fraction of the residues from maize (maize stover, maize cobs) is used by the household?		%
28	When household members have harvested the wheat crop, do they collect the residues (wheat straw) for any use?	Yes	Assign one choice
		No	
29	What fraction of the residues from wheat (wheat straw) is used by the household?		%
E	ON-FARM FOREST AND DOMINANT TREES		
30	Provide an estimate of the land size (acres) under natural forest or woodlot (naturally growing on farm).		Acres
31	Provide an estimate of the land size (acres) under planted (or managed) forest or woodlot (planted trees on-farm).		Acres
32	Provide the name of the main tree species in the natural forest or woodlot (naturally growing) on the farm.		
I	What is the name of the most dominant tree species?		English name (or local or botanical name)

Table G-1 | **Household survey protocol (cont.)**

#	VARIABLE	CHOICES	UNIT
II	What is the name of the second-most dominant tree species?		English name (or local or botanical name)
33	What is the name of the main tree species in the planted (or managed) forest or woodlot (planted trees on farm)?		English name (or local or botanical name)
F	LIVESTOCK HOLDING		
34	How many cattle does the family have?		# of cattle
35	How many days in a year are the cattle spending the night in the home boma?		# of days
36	How many small ruminants (sheep and goats) does the family have?		# of small ruminants
37	How many days in a year are the sheep and goats spending the night in the home boma?		# of days
38	How many poultry does the family have?		# of poultry
39	How many pigs does the family have?		# of pigs
40	How often is cow dung collected for use by the household? Specify if collected daily, once per week, once per month, or after more than 2 months.	Daily	Assign one choice
		Once per week	
		Every two weeks	
		Once per month	
		After more than 2 months	
41	What fraction of cow dung is collected for use by the household?		%
42	How often is the waste from small ruminants (sheep and goats) collected for use by the household? Specify if collected daily, once per week, once per month, or after more than 2 months.	Daily	Assign one choice
		Once per week	
		Every two weeks	
		Once per month	
		After more than 2 months	
43	What fraction of waste from small ruminants (sheep and goats) is collected for use by the household?		%
44	How often is waste from poultry collected for use by the household? Specify if collected daily, once per week, once per month, or after more than 2 months.	Daily	Assign one choice
		Once per week	
		Every two weeks	
		Once per month	
		After more than 2 months	
45	What fraction of waste from poultry is collected for use by the household?		%
G	FUEL TYPE AND CONSUMPTION		
46	What is the main source of energy used for lighting by the household?	Electric energy (includes generator, solar, mini-grid, KPLC, rechargeable batteries)	Assign one choice
		Dry cell batteries	
		Candles	
		Kerosene	
		Firewood/Open fire	
		Biogas	
		LPG	
		Ethanol	
		Other	

Table G-1 | **Household survey protocol (cont.)**

#	VARIABLE	CHOICES	UNIT
47	What is the main source of electricity used by the household?	Grid electricity (i.e. KPLC)	Assign one choice
		Local mini-grid	
		Solar home system	
		Solar lantern	
		Electric generator	
		Rechargeable batteries	
		Dry cells	
		Other	
48. a	What is the main device used for lighting by the household?	Electric bulbs	Assign one choice
		Torches	
		Tin lamps	
		Gas lanterns	
		Solar lanterns	
		Pressure lanterns	
		Open fire	
		Mobile phone	
		Candles	
		Other	
48.b	In the case of electric bulbs, what is the type of lighting bulb used by the household?	LED bulb	
		Energy saver	
		Incandescent	
		Halogen	
		Other	
49	What energy devices does the household have?	Radio	Assign appropriate choice(s)
		Television	
		Fridge	
		Fan	
		Electric kettle	
		Electric iron box	
		Mobile phone	
		Air conditioner	
		Other	
50	Indicate the amount spent (KES) by the household on electricity monthly.		KES
H	COOKING FUELS AND TECHNOLOGIES		

Table G-1 | **Household survey protocol (cont.)**

#	VARIABLE	CHOICES	UNIT
51	What is the household's main fuel(s) for cooking?	Electricity	Assign appropriate choice(s)
		Firewood	
		Charcoal	
		Biogas	
		Paraffin	
		LPG	
		Ethanol	
		Crop residues	
		Other	
52	Indicate the number of refills of LPG the household consumes per month. Please specify the size of the gas cylinder refilled and the cost for each refill.	This question will be asked only if the respondent gives LPG as a response.	# of refills
53	Indicate the litres of kerosene the household consumes per week. Also indicate cost per litre.	This question will be asked only if the respondent gives kerosene as a response.	# of litres
54	Indicate the quantity of charcoal the household uses in a single (normal) month.	This question will be asked only if the respondent gives charcoal as a response.	# of bags/tins
55	Indicate the quantity of firewood used in a single (normal) day by the household to cook or warm the house using the three-stone traditional cooking or warming place. Please specify the unit used to indicate quantity—e.g. kg; hand-piles (a bunch held under the armpit of an adult); back-piles (the bunch carried by women on their backs); stack-pile (the same 1 m^3 bunch of wood as is sold to tea factories)	This question will be asked only if the respondent gives firewood as a response.	# of kg, hand-piles, back-piles, or stack-piles
56	Among the above fuel options used by the household, where does the household get its main fuel type(s) from? Surveyor to prompt and assign the correct source(s). For this question, if the choice 'From own production or collection' is one of the answers, THEN provide answers to questions 57–59.	Purchase from local kiosks or vendors	Assign appropriate choice(s)
		Purchase from supermarkets	
		Purchase from marketplace	
		From own production or collection	
57	Indicate the number of firewood-gathering trips taken by the household in a week.		#
58	How far (estimate km) from the house does the household go to collect firewood? Surveyor to help in estimating distance.		km
59	Who is responsible for firewood collection in the household?	Head	Assign one choice
		Spouse	
		Daughter	
		Son	
		Niece/Nephew	
		Grandchild	
		Other (specify)	
60	How long (estimate hours) does it take to walk from the house to where the household collects firewood?		hrs
61	What means is household using to transport or ferry firewood back home? Surveyor to prompt various options and assign correctly.	Lorry	Assign appropriate choice(s)
		Tractor trailer	
		Bicycles	
		Handcarts	
		Draught animals	

Table G-1 | **Household survey protocol (cont.)**

#	VARIABLE	CHOICES	UNIT
62	How often does the household use animal waste (e.g. cow dung) as fuel for cooking or space heating? Surveyor to prompt and assign the correct answer.	Rare	Assign one choice
		Daily	
		Once per week	
63	How often does the household use crop residues (e.g. maize cobs, maize stover, wheat straws) as fuel for cooking or heating? Surveyor to prompt and assign the correct answer.	Rare	Assign one choice
		Daily	
		Once per week	
64	What type of stove does the household use as its primary stove? Surveyor to prompt and assign the correct answer(s).	Traditional three stone	Assign appropriate choice(s)
		Improved traditional stone (kuni mbili)	
		Ordinary jiko (metallic charcoal)	
		Improved jiko (e.g. Kenyan ceramic jiko, jiko okoa)	
		Type of gasifier (improved biomass)	
		Gas cooker (LPG)	
		Kerosene stove	
		Electric stove	
		Biogas stove	
		Other	
65	For each of the commonly used cookstoves, indicate how long the household has used it as its main stove. Surveyor to prompt and assign the correct answer.	Less than a year	Assign one choice
		1–3 years	
		Over 3 years	
66	For each of the commonly used cookstoves, indicate the frequency of use in terms of how many days in a week or in a month the stove is used. Specify if the unit used is per week or per month.		# of days (assigned in the respective column)
67	Indicate the number of times the three-stone traditional cooking stove is lit by the household per day (normal day).	If selected in question 64	#
68	Indicate the number of times the charcoal stove is lit by the household per day (normal day).	If selected in question 64	#
I	ENERGY EFFICIENCY AND CONSERVATION		
69	What does the household do to conserve energy during cooking?	Pull out firewood from the fire to prevent further burning	Multiple choice
		Put out charcoal when done cooking for future use	
		Cover cooking area to prevent heat loss	
		Use an improved cookstove to reduce energy consumption	
		None	
		Other	
70	What does the household do to conserve energy for lighting?	Switch off lights when not in use	
		Open doors and windows for natural lighting	
		Use fewer hours of lighting	
		None	
		Other	

Note: GPS = Global Positioning System; ID = identification; KPLC = Kenya Power & Lighting Company; LPG = liquefied petroleum gas; LED = light-emitting diode; kg = kilogramme; m^3 = cubic metre; km = kilometre; hrs = hours.

Source: Authors.

Appendix H. Replicating this methodology in other counties: Case study of Makueni County

OnSSET modelling for Makueni's CEP

This methodology was replicated to design the CEP for the county government of Makueni where OnSSET was used to model cost-effective electrification strategies for the county. The county aims to achieve universal access by 2028, with an alternative scenario for 2026, and maintain it through 2032 despite population growth.

Scenarios description

Three electrification scenarios for Makueni County were modelled: Low Demand (Scenario 1), High Demand (Scenario 2), and High Demand with Forced Grid Intensification (Scenario 3), targeting universal access by 2026 and 2028. We developed the scenarios to determine possible electrification pathways for Makueni County as shown in Table H-1.

By comparing the three scenarios (see Table H-2), Scenario 2 appears to be the most viable with the highest net benefit since it meets the high energy demand that could be exploited for other uses like Productive Use of Renewable Energy (PURE) but is cheaper than Scenario 3. The added capacity of Scenario 2 is also considerably higher. The county thus proposed to proceed with Scenario 2.

Table H-1 | **Key assumptions for the modelled scenarios**

ASSUMPTION CATEGORY	SCENARIO 1: DOMESTIC ELECTRIFICATION, LOW DEMAND	SCENARIO 2: DOMESTIC ELECTRIFICATION, HIGH DEMAND	SCENARIO 3: DOMESTIC ELECTRIFICATION, HIGH DEMAND, FORCED GRID INTENSIFICATION
Demand-side assumptions	▪ Normal/expected population growth at 1.1% ▪ Tier 1a demand for rural consumers and Tier 4 for urban consumers ▪ 100% electrification rate by 2028 ▪ 100% electrification maintained with additional demand due to population increase factored up to 2032	▪ High population growth at 2% ▪ High electricity demand target (Tier 3 for rural areas and Tier 5 for urban areas) ▪ 100% electrification rate by 2026 with another scenario reflecting universal access by 2028 ▪ 100% electrification maintained with additional demand due to population increase factored up to 2032	▪ High population growth at 2% ▪ High electricity demand target (Tier 3 for rural areas and Tier 5 for urban areas) ▪ 100% electrification rate in 2028 ▪ 100% electrification maintained with additional demand due to population increase factored up to 2032
Supply-side assumptions	▪ Low generating cost for the grid (0.047$/kWh) ▪ PV capacity cost as defined by the user ▪ Prioritisation of least-cost electrification technologies (grid, mini-grids, and solar home systems)	▪ High generating cost for the grid (0.059$/kWh) ▪ PV capacity cost reduced by 25% ▪ Prioritisation of least-cost electrification technologies (grid, mini-grids, and solar home systems)	▪ High generating cost for the grid (0.059$/kWh) ▪ PV capacity cost reduced by 25% ▪ Forced grid electrification for areas that are within 2 km of the grid and least-cost technologies for areas that are beyond 2 km

Note: a Tiers of demand are used to approximate demand in rural and urban areas and not to define electrification solutions. See Table 2 for more. $/kWh = dollars per kilowatt-hour; PV = photovoltaic; km = kilometre.
Source: Authors.

Table H-2 | **Comparison of results from the three scenarios**

PARAMETERS	SCENARIO 1: LOW DEMAND	SCENARIO 2: HIGH DEMAND	SCENARIO 3: HIGH DEMAND, GRID INTENSIFICATION
Capacity (MW)	21.6 MW	96.4 MW	38.4 MW
Investment cost (millions, $)	$132.5	$360	$571.8

Note: MW = megawatt.
Source: Authors.

After further consultations with the Makueni County officials, we further improved Scenario 2 by updating electricity demand to also include demand from non-residential buildings extracted from Open Building Insights (OBI) and from PURE projects in agriculture recommended by the county government.

Figure H-1 shows the locations of the additional loads added to the updated OnSSET model factoring in non-residential building demand from OBI and from PURE projects in agriculture.

Table H-3 lists the demand- and supply-side assumptions used in the updated Scenario 2 with energy demand from PURE projects in agriculture and non-residential building loads added to the model.

OnSSET model results with additional PURE loads

The map in Figure H-2 shows the least-cost overall technology choice per settlement in 2030 as per the modelling scenario selected with PURE demand in agriculture and non-residential buildings.

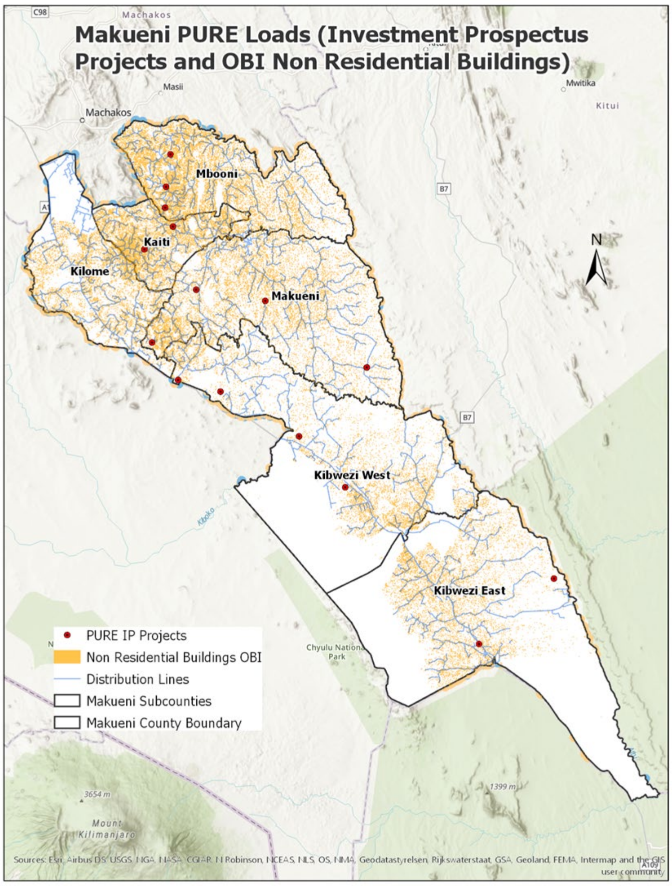
Discussion

This updated scenario factors in additional loads as described from non-residential buildings and PURE in agriculture besides the original scenario which considered only household electrification loads.

Thus, as expected, the total additional capacity required to meet the extra load is higher than that for the initial scenario, which covered only residential loads, at 115 MW versus 96.4 MW.

This also increases the total cost required to implement these electrification technologies from $360 million for the initial scenario to $421.1 million.

Figure H-1 | **Scenario 2 modelled with additional loads from PURE and non-residential buildings from Open Building Insights**



Note: OnSSET = Open Source Spatial Electrification Tool; PURE = Productive Use of Renewable Energy; IP = investment prospectus; OBI = Open Building Insights.

Source: SE4All and IBM n.d.

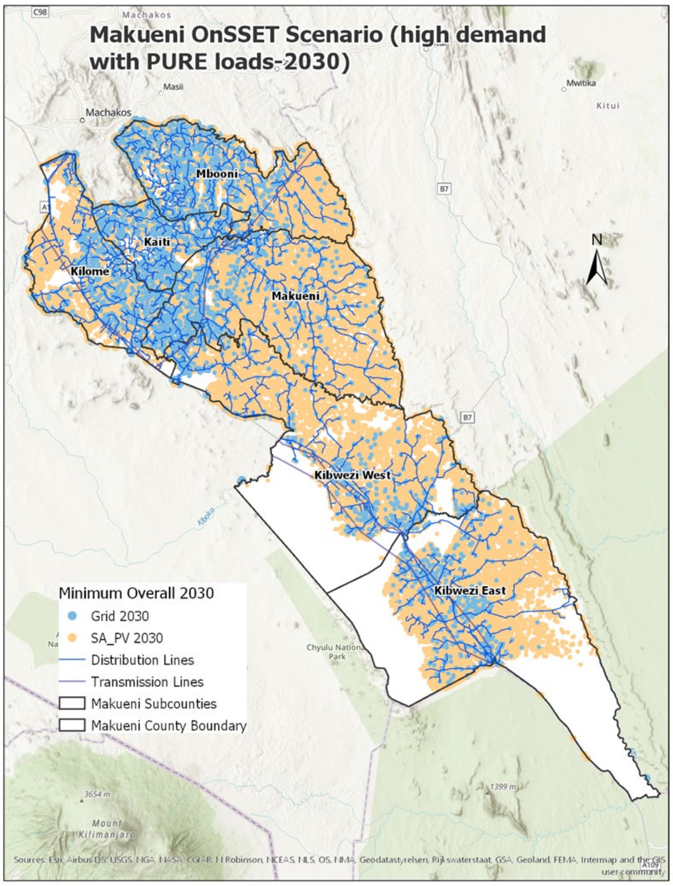
Table H-3 | **Key assumptions for updated Scenario 2**

ASSUMPTION CATEGORY	SCENARIO 2 WITH PURE PROJECTS IN AGRICULTURE AND NON-RESIDENTIAL BUILDING LOADS
Demand-side assumptions	▪ High population growth at 2% ▪ High electricity demand target (Tier 3[a] demand for rural areas and Tier 5 for urban areas) ▪ Demand from PURE projects in agriculture added ▪ Demand from non-residential buildings from OBI added ▪ 100% electrification rate in 2028 ▪ 100% electrification maintained with additional demand due to population increase factored up to 2030 (in line with Government of Kenya's Vision 2030)[b]
Supply-side assumptions	▪ High generating cost for the grid ▪ PV capacity cost reduced by 25% ▪ Prioritisation of least-cost electrification technologies (grid, mini-grids, and solar home systems)

Notes: [a] Tiers of demand are used to approximate demand in rural and urban areas and not to define electrification solutions. See Table 2.[b] VDS n.d. OnSSET = Open Source Spatial Electrification Tool; PURE = Productive Use of Renewable Energy; OBI = Open Building Insights; PV = photovoltaic.

Source: Authors.

Figure H-2 | **Output map of Makueni County's updated Scenario 2: Loads results**



Notes: Grid 2030 = Households for which the grid is the least-cost electrification solution in 2030; SA_PV 2030 = Households for which stand-alone photovoltaic (solar) is the least-cost solution in 2030. OnSSET = Open Source Spatial Electrification Tool; PURE = Productive Use of Renewable Energy.

Source: Authors.

Table H-4 | **Capacity required for electrification in Makueni County's updated Scenario 2**

TECHNOLOGY	2028 (MW)	2030 (MW)	TOTAL (MW)
Grid	57	5	62
Stand-alone PV	18	35	53
Total			**115 MW**

Note: MW = megawatt; PV = photovoltaic.

Source: Authors.

Table H-5 | **Investment required for Makueni County's updated Scenario 2**

TECHNOLOGY	2028 (MILLIONS, $)	2030 (MILLIONS, $)	TOTAL
Grid	223.8	17.4	241.2
Stand-alone PV	61.9	118	179.9
Total (millions, $)	**421.1**		

Note: PV = photovoltaic.

Source: Authors.

Endnotes

1. Mentis et al. 2020.

References

CLUB-ER and Carbon Trust. 2019. "Electrified Mini-Grid Localities in Africa." https://www.club-er.org/library/techno-economic-databases-324.html.

Colozzi, Marina. 2023. "KoBoToolbox." Confluence. https://humanitarian.atlassian.net/wiki/spaces/imtoolbox/pages/3190980609/KoBoToolbox. Last updated May 10, 2023.

Croome, Shauna. 2024. "Understanding the Time Value of Money." *Investopedia*. https://www.investopedia.com/articles/03/082703.asp. Last updated January 2024.

Data.org. n.d. "How WRI's Energy Access Explorer Empowers Inclusive Data-Driven Solutions." https://data.org/stories/energy-access-explorer/. Accessed July 3, 2024.

ESMAP (Energy Sector Management Assistance Program). 2015. *Beyond Connections: Energy Access Redefined*. Washington, DC: International Bank for Reconstruction and Development, World Bank Group. https://openknowledge.worldbank.org/server/api/core/bitstreams/248a7205-e926-5946-9025-605b8035ad95/content.

GoK (Government of Kenya). 2019. "The Energy Act, 2019." Nairobi: Government of Kenya. http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/2019/EnergyAct__No.1of2019.PDF.

Kipkemoi, Felix. 2024. "Energy Sector Celebrates Milestone as 16 Counties Progress with County Energy Plans." *The Star*, March 19. https://www.the-star.co.ke/news/realtime/2024-03-19-energy-sector-celebrates-milestone-as-16-counties-progress-with-county-energy-plans/.

KNBS (Kenya National Bureau of Statistics). 2016. "Socio-economic Data of Kenya." Kenya Open Data. https://kenya.opendataforafrica.org/SEDK2015/socio-economic-data-of-kenya-2011?region=1000630-narok&indicator=1011900-population-growth-rate.

KNBS. 2019. *Kenya Population and Housing Census: Volume IV.* Nairobi: Kenya National Bureau of Statistics. https://www.knbs.or.ke/download/2019-kenya-population-and-housing-census-volume-iv-distribution-of-population-by-socio-economic-characteristics/.

KPLC (Kenya Power & Lighting Company). 2017a. "Kenya Electricity Network." Via Energydata.info. https://energydata.info/dataset/kenya-kenya-electricity-network.

KPLC. 2017b. "Kenya Primary Substations." Via Energydata.info. https://energydata.info/dataset/kenya-primary-substations.

KPLC. 2017c. "Kenya Distribution Transformers." Via Energydata.info. https://energydata.info/dataset/kenya-distribution-transformers.

Mentis, Dimitris, Lily Odarno, Davida Wood, Fabian Jendle, Elise Mazur, Anila Qehaja, and Francis Gassert. 2019. "Energy Access Explorer: Data and Methods." Technical Note. Washington, DC: World Resources Institute. https://www.wri.org/research/energy-access-explorer-data-and-methods.

Mentis, Dimitris, Mark Howells, Holger Rogner, Alexandros Korkovelos, Christopher Arderne, Eduardo Zepeda, Shahid Siyal, et al. 2017. "Lighting the World: The First Application of an Open Source, Spatial Electrification Tool (OnSSET) on Sub-Saharan Africa." *Environ. Res. Lett.* 12 (085003). doi: 10.1088/1748-9326/aa7b29.

MoEP (Ministry of Energy and Petroleum, Government of Kenya). 2018. *National Energy Policy.* Nairobi: Ministry of Energy and Petroleum. https://kplc.co.ke/img/full/BL4PdOqKtxFT_National%20Energy%20Policy%20October%20%202018.pdf.

MoEP. 2020. "Draft Integrated National Energy Planning Framework." Nairobi: Ministry of Energy and Petroleum.

MoEP. 2021. *Least Cost Power Development Plan 2021–2030.* Nairobi: Ministry of Energy and Petroleum. https://communications.bowmanslaw.com/REACTION/emsdocuments/LCPD%202021.pdf.

MoEP. 2023. *Strategic Plan 2023–2027.* Nairobi: Ministry of Energy and Petroleum. https://energy.go.ke/sites/default/files/KAWI/strategicplan/MoE%26P%20Final%20Draft%20Strategic%20Plan%202023-2027%2007-06-2024.pdf.

Moksnes, Nandi, Alexandros Korkovelos, Dimitrios Mentis, and Mark Howells. 2020. "Corrigendum: Electrification Pathways for Kenya: Linking Spatial Electrification Analysis and Medium to Long Term Energy Planning." *Environ. Res. Lett.* 15 (12): 129501. https://iopscience.iop.org/article/10.1088/1748-9326/abc7de.

MRL (My Research Lab). n.d. "Sample Size." https://www.myrelab.com/learn/sample-size. Accessed August 8, 2024.

Ogeya, Mbeo, Jacqueline Senyangwa, and Fiona Lambe. 2021. "At What Price? The Political Economy of Mini-Grid Electricity Development and Deployment in Kenya." Climate Compatible Growth. https://climatecompatiblegrowth.com/wp-content/uploads/2021/09/5C-COP26-Policy-Brief.pdf.

Otieno, Victor, Douglas Ronoh, Dimitris Mentis, Sarah Odera, and Benson Ireri. 2022. "A Data Driven Approach to Integrated, Inclusive Sub-national Energy Planning in Kenya." Policy Brief. Climate Compatible Growth. https://climatecompatiblegrowth.com/wp-content/uploads/Sub-national-energy-planning-in-Kenya_COP27-Policy-Brief.pdf.

Pueyo, A., S. Bawakyillenuo, and H. Osiolo. 2016. *Cost and Returns of Renewable Energy in Sub-Saharan Africa: A Comparison of Kenya and Ghana*. IDS Evidence Report 190. Brighton, UK: IDS. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/20.500.12413/11297/ER190_CostandReturnsofRenewableEnergyinSubSaharanAfricaAComparisonofKenyaandGhana.pdf;jsessionid=8162AFBAB1DA2399DB72152506B6C1B8?sequence=1.

REREC (Rural Electrification and Renewable Energy Corporation). n.d. "Our Work." https://www.rerec.co.ke/transformer-maximization.php. Accessed March 19, 2023.

Sahlberg, Andreas, Alexandros Korkovelos, Babak Khavari, Oluchi Monwe, Dimitrios Mentis, and Christopher Arderne. 2020. "Introduction to OnSSET." https://onsset.readthedocs.io/en/latest/introduction.html.

SE4All and IBM (Sustainable Energy for All and International Business Machines Corporation). n.d. "Learn about Open Building Insights." https://websitebucket.s3.eu-de.cloud-object-storage.appdomain.cloud/about.html. Accessed June 21, 2024.

SEI (Stockholm Environment Institute). 2017. "The Long-Range Energy Alternatives Planning—Integrated Benefits Calculator (LEAP-IBC)." Fact Sheet. https://mediamanager.sei.org/documents/Publications/SEI-Factsheet-LEAP-IBC-2.pdf.

VDS (Vision Delivery Secretariat). n.d. "About Vision 2030." https://vision2030.go.ke/about-vision-2030/. Accessed November 19, 2024.

WRI (World Resources Institute). 2019. Energy Access Explorer. https://www.wri.org/initiatives/energy-access-explorer. Accessed March 21, 2023.

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