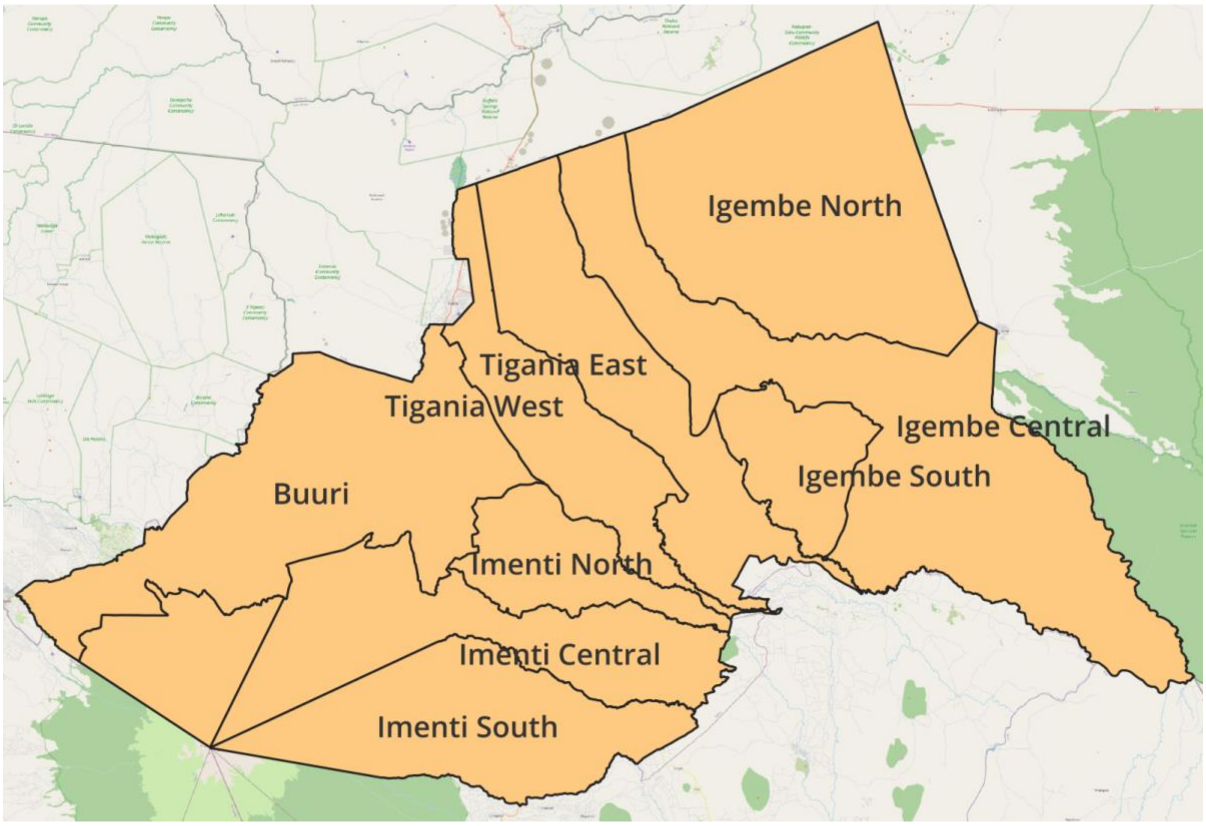

Meru County, Kenya Sub Counties

Working paper

Modelling needs-based county energy demand: A case study using Meru County CEP solutions

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13/10/2023

Executive Summary

This report is a companion piece to the *Working Paper on Tools and approaches to support needs-based demand assessment and investment in County Energy Planning in Kenya* (April 2023). It summarises the results of modelling work carried out to aggregate county energy demand from Meru County Energy Plan (CEP) solutions.

The Meru CEP solutions were developed using the inclusive, cross-sectoral Energy Delivery Models (EDM) planning approach where energy services are designed as enablers of wider development needs. In the Meru case, six priority sectoral solutions were developed across household lighting access, clean cooking, access to health, access to water, improved income from crop farming and from poultry farming.

The overall aim was to explore how OnSSET modelling could be used to build a more real-world, needs-based picture of energy demand for Meru County. A further aim was to explore if this picture of aggregate demand changed the choice of technology mix for least cost electrification.

This report first briefly outlines context and enabling environment in Kenya for county energy planning, including the new draft Integrated National Energy Planning (INEP) Framework.

The report then describes the OnSSET modelling tool, including the geo-spatial data sets and techno-economic parameters required for the modelling, before outlining the methodology used for this modelling exercise.

The modelling exercise focussed on the solutions categorised here as productive uses of energy (PUE) - health, poultry farming, crop farming and water – beyond household electricity. The first step was to quantify the annual energy demand from the various PUE solutions. The second was to develop a method for estimating the locations for implementation of the priority solutions where these had not yet been determined by the county government.

The cumulative PUE annual energy demand across the different sub-counties was then calculated. Water solutions had the highest annual energy demand of 5.9GWh, followed by demand for crop farming solutions (3.5 GWh). The annual demand for health and poultry solutions was 0.5 GWh and 0.2 GWh respectively.

To determine whether inclusion of PUE impacts the least cost electrification (LCE) technology mix, two scenarios were modelled, **Scenario 1** which involved household electrification without inclusion of PUE and **Scenario 2** which involved the electrification of households and electrification of PUE. The results were as follows:

- Adding the productive uses of energy increased the total required new capacity by 15.3% from 16,714kW to 19,279kW (in rural areas only).
- Inclusion of PUE had a great impact on the electrification technology mix. Without PUE, the LCE only involved grid and standalone PV systems. However, the inclusion of PUE showed 40 minigrids to be least cost technologies.
- The investment cost required for 100% electrification without PUE was USD 569.5 million. Adding PUE increases this cost by USD 4.1 million to 573.6 million. The addition of PUE reduces the cost per kW of new capacity by 12.7% from USD 34,075/kW to USD 29,753/kW

The findings of the modelling can be summarised as follows:

- It is possible to develop a methodology to give a more needs-based picture of county energy demand. This could be replicated across other counties.
- A notable finding is that the inclusion of the PUE in the determination of LCE changes the electrification mix, and in this case makes mini-grids viable, reducing the average cost per kW of new capacity.
- For this modelling, it is critical that methodologies used to develop CEPs identify the power requirements and either the specific locations for the energy demand or sufficient information on target end users and location types to select eligible regions, to make the CEP outputs compatible with geospatial energy modelling tools such as OnSSET.
- In terms of the OnSSET modelling tool itself, this could be strengthened by developing a new method for generating the OnSSET clusters that allow for productive uses located further from households to be their own clusters.
- It is also important to note that how the OnSSET model calculates the final investment costs should be checked or “ground truthed” to determine what is the actual least cost electrification scenario given the local context.

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List of Acronyms

ADP	ANNUAL DEVELOPMENT PLAN
CEP	COUNTY ENERGY PLAN
CIDP	COUNTY INTEGRATED DEVELOPMENT PLAN
CSV	COMMA-SEPARATED VALUES
EDM	ENERGY DELIVERY MODELS
GIS	GEOGRAPHIC INFORMATON SYSTEM
IED	INNOVATION, ENERGIE, DÉVELOPPEMENT
IIED	INTERNATIONAL INSTITUTE FOR ENVIRONMENT AND DEVELOPMENT
INEP	INTEGRATED NATIONAL ENERGY PLAN
LCE	LEVELISED OR LEAST COST ELECTRIFICATION
KPLC	KENYA POWER AND LIGHTING COMPANY
MoEP	MINISTRY OF ENERGY AND PETROLEUM
MTF	MULTI-TIER FRAMEWORK
OnSSET	OPEN-SOURCE SPATIAL ELECTRIFICATION TOOL
SDG	SUSTAINABLE DEVELOPMENT GOAL
SETA	SUSTAINABLE ENERGY TECHNICAL ASSISTANCE PROGRAMME

1 Introduction

This working paper is a companion piece to four previous working papers on *Data Needs for County Energy Planning in Kenya* and *Vertical Collaboration for County Energy Planning in Kenya* (October 2022) and in particular, *Tools and approaches to support needs-based demand assessment and investment in County Energy Planning in Kenya* (April 2023) and *Awareness of GESI in county energy planning in Kenya and approaches to integrating GESI in County Energy Plans* (October 2023).

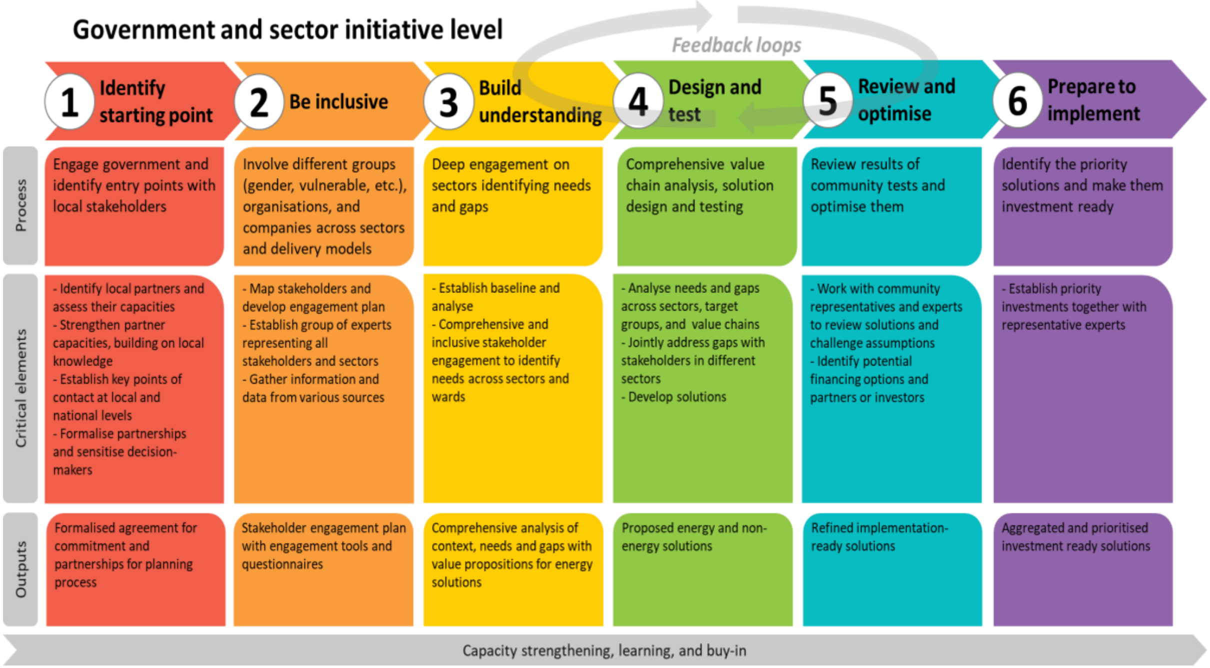
This report outlines the findings of future work referred to in the Working Paper on *Tools and approaches to support needs-based demand assessment and investment in County Energy Planning in Kenya* (April 2023), namely **Activity Four – estimating aggregate county energy demand from Meru County Energy Plan (CEP) solutions:**

1. The team will use modelling tools (e.g., OnSSET) to aggregate the energy components of all the CEP solutions to estimate the "energy demand" or potential load in particular locations (ward or sub-county). The team will then estimate the least cost electrification options for each location and identify the agency or level of government to deliver them.
2. Map potential locations for market centres, informed by the deployment of the EDM solutions and other data inputs, and their associated energy demand profile, as well as other sectors not identified as priorities during the EDM CEP process (e.g., education).
3. Depending on time and resource, explore options for the development of a web-based interactive tools (or a GUI) to communicate the modelling for implementation planning and investment decision making.

The team involved in this work includes the international leads of the EDM team, based at Loughborough and IIED, who have been working on county energy planning in Kenya since 2018, one of the National Mentoring Experts (NMEs) supporting counties with energy planning under the SETA Programme based at the Institute of Energy Research and Studies (IESR) of the National power company, KPLC, and a UK PACT researcher based at Oxford University. The latter two team members are experienced in using various energy planning tools such as GIS mapping and OnSSET modelling,

The Meru CEP has developed holistic solutions designed to meet the priority development needs identified by Meru County Government and citizens that integrate both energy and non-energy components using the Energy Delivery Models (EDM) planning process

The EDM approaches energy as an enabler of wider development needs. Through a six-step process (see Figure 1), EDM systematically identifies the priority needs of end uses (in this case, county citizens) and the gaps or barriers preventing these priority needs being met. These gaps can involve energy or other, non-energy factors (e.g., cost of inputs or access to markets for farmers). EDM then works with end users and other stakeholders to develop context-appropriate and costed solutions for inclusion in the CEP, and to inform Least Cost Electrification (LCE) and energy efficiency (EE) investments. The end product is should be fully-costed, socially and environmentally sustainable business and investment models.



	1 Identify starting point	2 Be inclusive	3 Build understanding	4 Design and test	5 Review and optimise	6 Prepare to implement
Process	Engage government and identify entry points with local stakeholders	Involve different groups (gender, vulnerable, etc.), organisations, and companies across sectors and delivery models	Deep engagement on sectors identifying needs and gaps	Comprehensive value chain analysis, solution design and testing	Review results of community tests and optimise them	Identify the priority solutions and make them investment ready
Critical elements	- Identify local partners and assess their capacities - Strengthen partner capacities, building on local knowledge - Establish key points of contact at local and national levels - Formalise partnerships and sensitise decision-makers	- Map stakeholders and develop engagement plan - Establish group of experts representing all stakeholders and sectors - Gather information and data from various sources	- Establish baseline and analyse - Comprehensive and inclusive stakeholder engagement to identify needs across sectors and wards	- Analyse needs and gaps across sectors, target groups, and value chains - Jointly address gaps with stakeholders in different sectors - Develop solutions	- Work with community representatives and experts to review solutions and challenge assumptions - Identify potential financing options and partners or investors	- Establish priority investments together with representative experts
Outputs	Formalised agreement for commitment and partnerships for planning process	Stakeholder engagement plan with engagement tools and questionnaires	Comprehensive analysis of context, needs and gaps with value propositions for energy solutions	Proposed energy and non-energy solutions	Refined implementation-ready solutions	Aggregated and prioritised investment ready solutions

Figure 1: Energy Delivery Model (EDM) 6-step government and sector-level process for county energy planning. Source: Garside & Perera (2021)

For the Meru CEP, the following six areas of priority development need were identified:

1. Improved income from horticulture Farming
2. Improved income from poultry farming
3. Access to clean and affordable water
4. Access to basic health services
5. Access to better quality household lighting and to street lighting
6. Access to affordable, cleaner, safer and reliable cooking fuels and technologies for households

The overall aim was to explore how OnSSET modelling could be used to build a more real-world, needs-based picture of energy demand for Meru County by modelling those energy services required to implement solutions to meet the priority needs developed in six sectors – or in those sectors where this was possible, given (a) the level of specificity of the solution in terms of modelling of the future power supply and load required to implement the solution during a five to ten year horizon; and (b) the level of specificity on where (the locations across the County) where the solutions would be implemented. See Section 3 on Methodology.

A further aim of the modelling activity was to explore if aggregation of the power requirements to implement more than one solution in particular locations changed the choice of technology.

This demand assessment will not cover *all* economic sectors in the county and *all* potential demand for energy services. The EDM process is explicitly designed for planners and end users (county government and citizens) to identify and *prioritise* development needs, in function of the reality of limited resources available from county and national budgets and other sources of financing.

Overall the aim is to develop a picture of demand that could be a useful input for national level energy systems modelling, as well as a tool to inform investment planning and decision-making by county governments.

2 Context and enabling environment for energy planning in Kenya

Energy planning in Kenya is now a mandate of both the national energy service providers (NESPs), such as the Kenya Power and Lighting Company (KPLC), led by the Ministry of Energy and Petroluem (MoEP), and the 47 county governments under the Fourth Schedule of the Constitution of Kenya (2010), and the Fifth Schedule of the Energy Act (2019). Under the Energy Act, the national government is required to develop an Integrated National Energy Plan (INEP) and county governments, MoE and NESPs are mandated to develop county energy plans as inputs to the design of the INEP.

However, both Kenya’s Energy Policy (2018) and subsequent research have identified several challenges to achieving integrated planning, including significant gaps in the data sets needed for both county and national energy planning, as well as data governance issues, and weaknesses in coordination between national and county level actors. The two working papers produced previously under the UK PACT Project, *Data Needs for County Energy Planning in Kenya* and *Vertical Collaboration for County Energy Planning in Kenya* (October 2022) have analysed these challenges in some depth and the Ministry of Energy has in response made important changes to the draft regulations or Framework for Integrated National Energy Planning (INEP) being developed to guide NESPs and county governments on their planning functions and mandates.

2.1 INEP Framework for Energy Planning

The INEP Framework has been under development since 2021 and is still under discussion by the MoE, associated state agencies and other stakeholders, including the Council of Governors as the umbrella body representing Kenya’s county governments. The latest version of the Framework reviewed by the LU team dates from February 2023. This iteration contains significant improvements to the INEP structure and functions, including two new sections on *Coordination* and *Data Management* which contain many of the recommendations from the two Working Papers produced under the UK PACT Project.

The INEP Framework recognises the energy planning now takes place in the context of Sustainable Development Goal (SDG)7 on access to affordable, reliable, sustainable and modern energy for all, and that “to provide reliable and affordable energy for all, there has to be a paradigm shift from the traditional energy planning to adequately respond to the evolving global energy market, [and] the changing roles and responsibilities across the energy value chain.” (INEP Foreword).

INEP further recognises that “the energy sector is a major enabler of wider economic & social development” (1.8.2). Thus, the INEP appears to acknowledge the increasingly accepted view, that energy planning and service delivery should not be a standalone, siloed process but address “wider societal goals” as expressed in international, national, sub-national (& regional) development goals and plans. At the county level, the INEP Framework specifically references the County Integrated Development Plans (CIDPs) that counties produce every five years as their development programming blueprint, and which inform the production of Annual Development Plans (ADPs) and budgetary allocation (1.8.1).

Furthermore, the Framework recognises that this will "[c]hallenge long-standing assumptions [and] rules-of-thumb in traditional energy planning [….] The traditional energy value chain was linear with energy carriers produced centrally and distributed to a passive end user." (1.2). This assumed passivity of the end user in energy planning is no longer acceptable". The Framework further states that: "Increasingly, environmental regulations, low-cost energy resources, *customer preferences and investments*, and risk management will drive investment decisions" (1.2, emphasis added). Thus, the INEP appears to recognize in principle the need for active participation of customers or end users in the planning of services and that these services should be designed to meet their needs, along with other societal considerations such as environmental sustainability.

The INEP stipulates a process for developing county energy plans (CEPs) and mandates the content of CEPs. Based on the understanding that previous energy planning prior to INEP has been top-down and the sole purview of the MoEP and its associated agencies at the national level, there is a need to ensure that planning approaches and tools are fit for purpose, if truly integrated, inclusive and also cross-sectoral - given the enabling role of energy in sustainable development – energy planning is to be achieved.

2.2 Current support for county energy planning

Different stakeholders are currently supporting county governments to develop their county energy plans using different planning approaches/methods and tools. These stakeholders include the MoE through the Sustainable Energy Technical Assistance (SETA) project, the World Resources Institute (WRI), and Strathmore University. Development organizations such as GIZ, WWF, and SNV are also funding county energy planning processes. One of the most recent programmes targeting a large number of actors involved in energy planning is the SETA Project.

The SETA project (2020-23) aims to assist the national energy institutions and the county governments through a comprehensive capacity development program in developing resilient and implementable sustainable energy plans under the INEP Framework.[1] SETA is a partnership with the MoEP and is funded by the European Union. SETA is led by Innovation, Energie, Développement (IED) and Practical Action. The Centre for Sustainable Transitions (STEER) at Loughborough University and the International Institute for Environment and Development are project partners. The intended impacts of the SETA project are the following:

- Improved capacity of the energy sector actors and other stakeholders at the national and county level for integrated planning, developing and implementing RE, EA, and EE projects.
- More effective engagement in energy planning of the private sector and CSOs, and vulnerable and poor groups, mainstreaming of gender, climate change, environment, and other critical issues.

SETA has adopted the Energy Delivery Model (EDM) methodology (see Section 5) as a means of both designing the first generation of CEPs in 12 counties (under what is termed the Advanced Training Programme or ATP) and more widely strengthening the understanding of inclusive and cross-sectoral planning approaches among other counties (46 counties participated in a Basic Training Project) and national actors (including MoE and other national service providers, the Council of Governors, private

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[1] See https://www.seta-kenya.org.

sector and civil society organisations). This includes ongoing discussion with officials in the MoE and other agencies involved in developing the INEP Framework.

Under SETA, Meru County was chosen as the “demonstration” county where a full EDM planning process will be carried out, and where the planning activities under the six-step process will be “mirrored” by a further 11 counties, supported by classroom training sessions. The next section explores different energy planning approaches, to give the context and rationale for why the EDM planning approach was developed as a response to perceived need for alternative approaches to traditional energy planning and delivery approaches in order for energy services to deliver more optimal development outcomes, and to meet the SDG 7 target of universal access to affordable, reliable and sustainable modern energy by 2030.

3 Methodology

3.1 The OnSSET modelling tool

This modelling tool used for this work was version 2 of the open-source geospatial electrification tool or OnSSET (see Box 1) , which allows the user to model for electrification of both households and productive uses of energy (PUE). PUE refers to the energy demand beyond the household (e.g., energy for lighting and cooking), such as the sectoral solutions for crop farming, poultry farming, water for dual use (e.g., farming and households), and was also used to cover energy demand for community services, such as health for the Meru CEP.

OnSSET is a bottom-up medium to long-term optimization model which uses population settlement cluster cells, together with different geospatial characteristics and socio- and tecno-economic data, to identify the least-cost supply option to reach universal electrification in each cluster.

The model relies on an electrification algorithm to identify and select the electrification technology configuration with the lowest Levelized Cost of Electricity (LCE). A GIS analysis produces a CSV file referencing the centroid of each population cluster cell in x and y coordinates. The CSV file includes additional information on demand, resource availability, infrastructure and economic activities.

The first step in the modelling process is establishing the baseline electricity access levels. The calibration uses a night-time lights dataset and geospatial data for the existing power network. The output of the initial calibration is binary; a settlement is either electrified or not. The resultant CSV file is then used to run the electrification scenarios, leading to proposed least-cost electrification options for each settlement cluster.

The electrification algorithm calculates the cost of generating electricity at each cell for seven different technology configurations (grid, PV minigrid, wind minigrid, hydro minigrid, diesel minigrid, PV standalone system and diesel standalone system), depending on a number of factors, including the demand, local resource availability, topography and infrastructure requirements. The LCE of a specific technology configuration represents the final cost of electricity required for the overall system to break even over the project's lifetime. The technology with the lowest LCE is then selected.

Source: Mentis, Howells, Korkovelos and Arderne, 2017

Box 1: Using OnSSET for least cost electrification (LCoE) modelling

See **Annex 1** for more information on the geospatial datasets used in OnSSET, their purpose, and the data sources used for modelling LCE for assessing Meru County energy demand (see also Mwenda et al, 2022).[2]

Apart from the geospatial data and the socio-economic parameters, OnSSET requires techno-economic inputs related to the cost of off-grid technologies and of grid operation and extension in order to run the least-cost electrification analysis. **Annex 2** gives more information on the techno-economic parameters used in the OnSSET modelling.

1.2 Quantifying energy demand from the EDM solutions

In developing the energy components of the solutions for the Meru CEP, demand is quantified by considering the power demand and the time of use of the energy-consuming equipment required to implement the solutions For instance, the power requirements for different tiers of household lighting access, or in the health solution, the amount of power required to run a certain minimum level of equipment and appliances needed to deliver “good enough” services in Level 2 health facilities (dispensaries delivering basic outpatient services, usually in rural areas). Not all the solutions developed had reached the level of detail to quantify the demand to the same level (see below).

For this work, it was decided to focus on PUE solutions alongside household electrification. Household electrification was integrated in the model by targeting electrification of rural households to Tier 1 electricity and urban households to Tier 4 electricity, according to the Multi-Tier Framework (MTF) (ESMAP, 2022). It should further be noted that a different method of LCE modelling, using OnSSET but also another LCE modelling tool, had been carried out under the CEP for the lighting solutions, along with additional contextual research, to identify the costs of connecting different end user groups to Tiers 1-4 of of household access. Future work would entail harmonising these different approaches to see how to develop a methodology that could identify the most realistic technology mix and cost scenarios.

3.1.1 Locating demand for productive uses of energy

For the inclusion of PUE in OnSSET analysis, the location coordinates of the PUE are required. Not all the solutions developed for the Meru CEP had the location coordinates included. Among the remaining four priority solutions, only poultry and health solutions had the precise locations for implementing the solutions given, as for the other solutions (crop farming and water) further discussion and decision-making by county government is required to select the precise target users and specific locations for each phase of implementation.

Thus the first task was to develop a methodology for estimating the locations where the water and crop farming solutions would most likey be implemented. In addition, while the annual energy demands for the poultry and health solutions had been developed previously (see the companion working paper on *Working Paper on Tools and approaches to support needs-based demand*

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[22] Note that most of the datasets are available at national level. As such, geoprocessing tools were used to clip the datasets to only include those within the Meru County boundaries.

assessment and investment in County Energy Planning in Kenya (April 2023), the annual energy demands for water and crop production had to be estimated, for the reasons discussed above.

Once the location and the annual energy demand of the PUE were determined, the LCE analysis was run on OnSSET to determine how the inclusion of the PUE impacts the electrification technology mix.

4 Using OnSSET to model aggregate demand

4.1 Health Solutions

The health solution modelled data based on the draft health solution aiming at electrification of 160 level 2 facilities without reliable electricity supply in Meru county. GIS mapping had been carried out as part of the health solution development. Annual energy demand from electrification of all unelectrified L2 facilities identified was calculated to be 3,339 kWh (Mwendwa, Onsare and S. Wykes, 2023). It should be noted that this solution has since been finalized to cover 160 L2 facilities without reliable electricity, thus if the modelling were to integrate this additional estimated demand, it could further impact the electrification technology mix.

4.2 Crop Farming Solutions

The solution is intended to increase income for target farmers who are beginning to experience water stress from climate change impacts through high value crop production, and has a large component of introducing more sustainable water management including through drip irrigagtion and water metering (Meru County Government, 2023). The targeted farmers were those within 300m of permanent rivers and the solution is to be implemented in two phases. Phase 1 will target 150 farmers while Phase 2 will target 3000 farmers. The farms plots were intended to be either 0.25 acres or 1 acre. The ratio of 0.25-acre plots to 1-acre plots was 2:1. Mixed farming was expected with the farmers growing tomatoes in the first season, kale in the second season and sweet potatoes in the third. Crop rotation was to be practised as it optimises farmer income. 0.25-acre pieces of land were proposed to need two 310W solar panels while the 1-acre pieces of land were proposed to need four 250W solar panels (ibid).

While the types of farmers and their distance from water sources has been modelled in the solution (Garside and Leone, 2023), the precise farmer groups and locations of the targeted farms has not yet been determined. Thus the methodology involved developing proxy locations for where the farms could be, based on the solution target end user criteria, and, on 30mx30m polygons of analysis. The eligible areas were selected using the following criteria:

- The distance to the nearest permanent river being less than 300m.
- The area being categorised as a cropland according to the International Food Policy Research Institute dataset (2017).
- The area being categorised as a growing area for vegetables or sweet potatoes (ibid).

Using these criteria gave an area of 153 km^2 of land that is eligible for the irrigated crop farming solution.

As the target number of end users for the solution was 3,150 farmers, the eligible area was divided into 3,150 equal regions and the midpoint of each region assumed to be the location of each of the farms to be irrigated. The distribution of farmlands among the different sub-counties in Meru is shown in Table 1. It should be noted that were no farms selected in Igembe North, Igembe South and

Igembe central as these regions did not meet the criteria. The selected farms are as shown in Figure 2.

Subcounty	Number of Farms
Buuri	277
Imenti Central	925
Imenti North	800
Imenti South	501
Tigania East	312
Tigania West	335

Table 1: Distribution of number of farms to be irrigated per sub-county

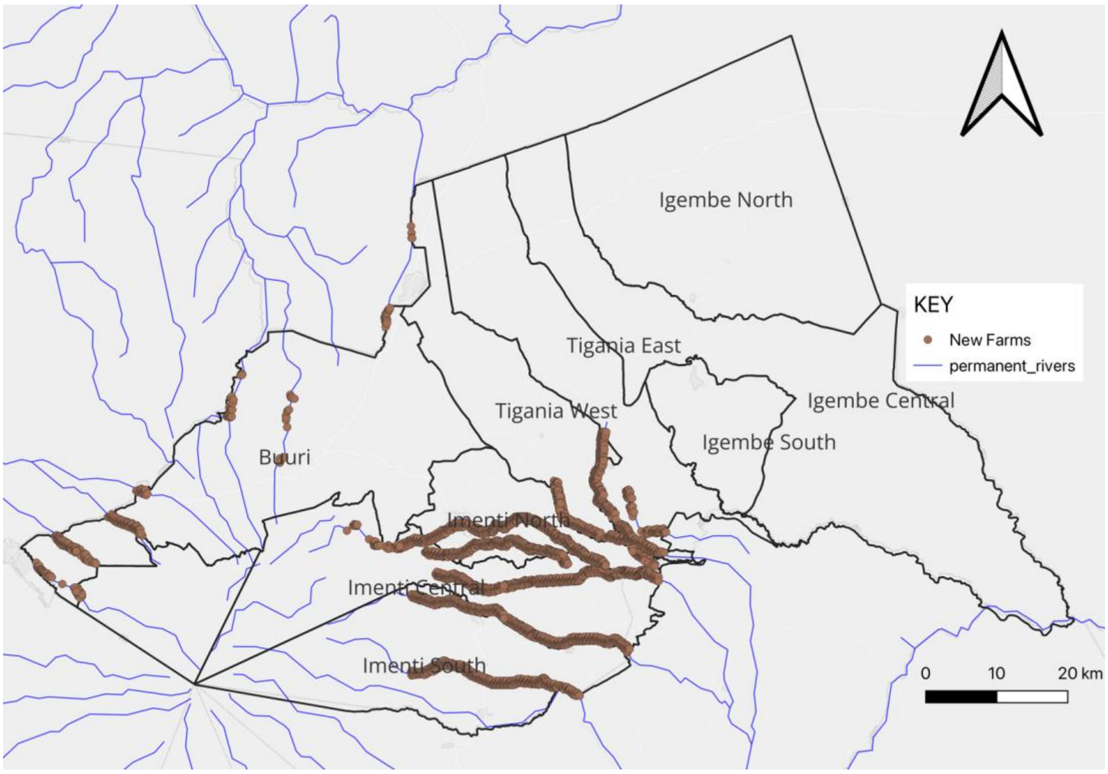

Figure 2: Permanent rivers and farmlands selected for irrigation.

The annual energy demand for the farms was estimated based on the modelling for the crop farming solution) of the number of solar PVs needed for the 0.25 acre farms (2x310W) and those needed for the one acre farms (4x250W) (Meru County Government, 2023. Assuming a capacity factor of 50% for the panels during the day and that they are used for 8 hours a day, the annual energy demand was approximated to be 900kWh for the 0.25 acre farms and 1500kWh for the one acre farm.

These numbers are clearly an approximation as the irrigation demand will not be at peak throughout the year, but to run the OnSSET model, thes figures make sense as they will be used for sizing the system that is needed.

4.3 Water Solutions

The water solution had three main energy/infrastructure components, in addition to establishing maintenance and repair functions, and non-energy components such as establishing best practice water committees, introducing metering and charging, training and awareness raising of end users etc (Meru County Government, 2023):

- Solarization of 20 existing boreholes.
- Drilling and powering new boreholes. The plan was for 127 new boreholes in Phase 1 of solution implementation, and 224 new boreholes in Phase 2.
- 20 pilot community water purification centres.

As the names of the 20 boreholes to be electrified were provided, their locations were estimated by using google maps. The distribution of the 20 boreholes per sub-county is as shown in Table 2.

Sub county	**Number of boreholes**
Igembe Central	15
Igembe North	4
Tigania West	1

Table 2: The distribution of the existing boreholes to be electrified per sub county.

However, the exact location of the new boreholes was not given. These were estimated using the following criteria:

- Meru county was divided into 0.5kmx0.5km polygons.
- The distance of each polygon centroid from the nearest borehole was calculated.
- Polygons beyond 1km of the nearest boreholes and with population density greater than 100pp/km2 were categorised to be eligible for a new borehole.

This method produced 1,500 1km^2 regions eligible for the 351 recommended new boreholes. To allocate where the new boreholes should be located, the number of boreholes proposed per sub-county was used with an equal distribution around the eligible sub-county polygons. The proposed number of boreholes per subcounty using this method was as shown in Table 3.

Sub county	**Phase 1 boreholes**	**Phase 2 boreholes**	**Total boreholes**
Buuri	33	57	90
Igembe Central	26	51	77
Igembe North	11	56	67
Igembe South	26	28	54
Tigania East	31	32	63

Table 3: Distribution of new boreholes among Meru sub counties.

The location of the 20 water purification centres was selected based on the total dissolved solids (TDS) levels mapped in the solution analysis. The purification centres were distributed among areas where borehole water has TDS levels greater than 1000 mg/l. In terms of the sub counties, the distribution of the water purification centres was as shown in Table 4. The final locations of the water solutions were as mapped in Figure 3.

Sub county	**Number of water purification centres**
Buuri	2
Igembe Central	4
Igembe South	3
Tigania East	5
Tigania West	6

Table 4: Distribution of water purification centres among the Meru sub counties.

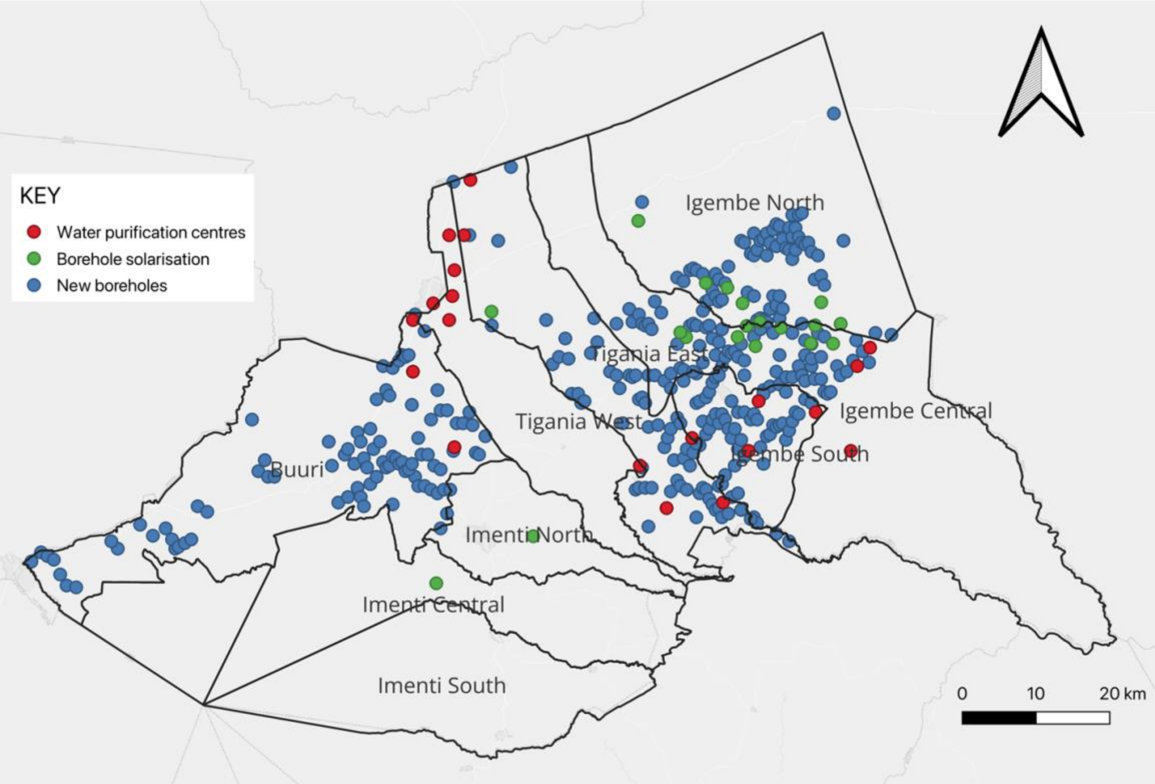

Figure 3: Locations for boreholes and water purification centres.

The power demand for water pumping can be calculated using Equation 1 (from Guzman et al, 2018).

$$P = \frac{Q\rho gH}{n_{pump}} \times 10^{-3}$$ Equation 1

Where P is the power in kW, Q is the maximum water flow rate in m^3/s, ρ is the water density in kg/m^3 (taken to be $1000kg/m^3$), g is the acceleration due to gravity (taken to $10m^2/s$), H is the dynamic water head in metres and n_{pump} is the pump efficiency.

Annual energy demand was determined by assuming that the boreholes would be used for 7 hours a day with an annual availability of 80% [5]. The pump efficiency was assumed to be $\sim$ 50% (using Santra, 2021 as well as the solution analysis carried out). The borehole yield (which was taken to be the possible maximum flow rate) and the water head for different sub counties were as shown in Table 5 (using the modelling carried out for the solution).

Sub county	Yield (m3/hr)	Depth	Peak Power Demand (kW)	Annual Energy Demand (kWh)
Igembe North	12	200	13	26,590
Igembe Central	8	200	7.5	15,341
Igembe South	8	200	7.5	15,341
Tigania East	8	200	7.5	15,341
Tigania West	12	200	13	26,590
Buuri	5	200	4	8,182

Table 5: Borehole parameters for Meru sub counties.

The water purification machine chosen has two components, a low-pressure pre-treatment pump with power demand of 2.2kW and a high-pressure reverse osmosis pump with an energy demand of 7.5kW giving a combined peak demand of 9.7kW [5]. The determination of the annual energy demand was based on the hours of operation per day which was in turn influenced by the expected daily flow rate. An availability rate of 80% was used and a year taken to have 365.25 days. The annual energy demand for the various sub counties was obtained as shown in Table 6.

Subcounty	Daily Feed (m3)	Peak Power (kW)	Operating hours per day	Annual energy demand (kWh)
Buuri	9.6	9.7	4	11,337
Igembe Central	9.6	9.7	4	11,337
Igembe North	9.6	9.7	4	11,337
Igembe South	14.4	9.7	6	17,006
Tigania East	14.4	9.7	6	17,006
Tigania West	9.6	9.7	4	11,337

Table 6: Parameters for water purification in Meru sub counties

4.4 Poultry Solutions

The poultry solution involved providing reliable electrification for four model villages, scaling up from one MV in the demo phase to four over the course of the CEP, and targeting around 800 farmers (in addition to an individual farmer model using solar incubation) . The villages MVs all required incubators, brooder heating, brooder lighting, feed millers and feed mixers which would all be electrically powered. There were specific locations for the MVs and the annual energy demand per MV was calculated to be 50,000 kWh (Mustiso, Mwenda, Onsare and Wykes, 2023).

5 Summary of OnSSET PUE inputs

The final OnSSET input file for productive uses for the various Meru sub counties is shown in Table 7. The cumulative PUE annual energy demand across the different sub-counties is shown in Figure 4. Water solutions had the highest annual energy demand of 5.9GWh, followed by demand for crop farming solutions (3.5 GWh). The annual demand for health and poultry solutions was 0.5 GWh and 0.2 GWh respectively. The percentage weights of the PUE demand for the various solutions was as shown in Figure 5.

Sub county	Health (kWh)	Agriculture (kWh)	Water (kWh)	Poultry (kWh)	Total (kWh)
Buuri	40,068	306,000	780,583	50,000	1,176,651
Igembe Central	33,390	0	1,272,502	50,000	1,355,892
Igembe North	56,763	0	1,736,544	0	1,793,308
Igembe South	43,407	0	889,076	0	932,484
Imenti Central	63,441	1,037,400	15,340	0	1,116,182
Imenti North	40,068	997,500	23,522	50,000	1,111,090
Imenti South	100,170	532,800	0	0	632,970
Tigania East	53,424	358,800	1,062,731	0	1,474,955
Tigania West	66,780	316,200	81,874	50,000	514,854
Total	497,511	3,548,700	5,862,175	200,000	10,108,386

Table 7: Annual energy demand (kWh) for the PUE in Meru sub counties

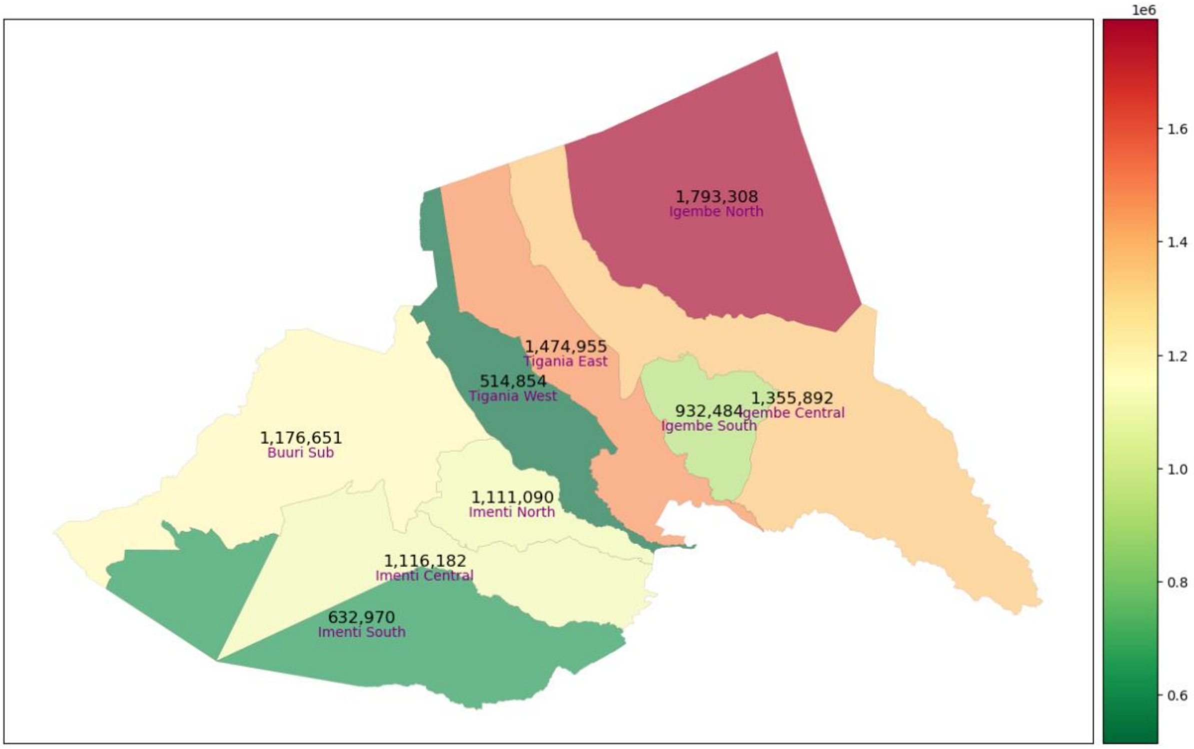

Figure 4: Cumulative annual energy demand (kWh) for Meru sub counties.

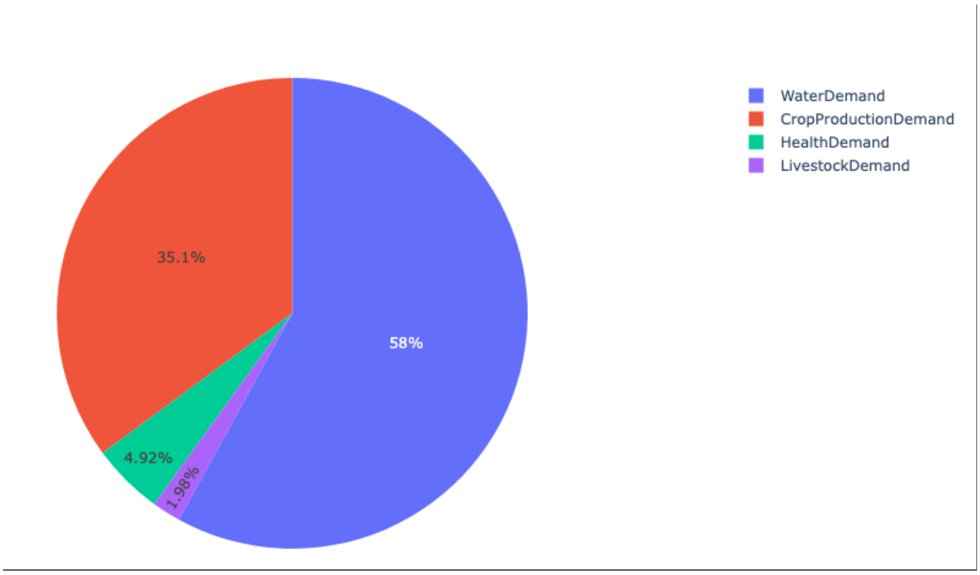

Figure 5: Percentage demand for water, agriculture (crop production), health and poultry (livestock) solutions.

There was no demand for agriculture (irrigation) in Igembe Central, Igembe South and Igembe North as there are no permanent rivers close to croplands in these sub-counties and therefore irrigation from rivers was not considered feasible. The highest energy demand for irrigation was in Imenti Central (1.04 GWh) followed by Imenti North (0.998 GWh). The highest energy demand for water solutions was found in in Igembe North (1.7GWh), Igembe Central (1.3GWh) then Tigania East (1.06GWh). The total annual demand from PUE is 10.1GWh.

6 Modelling Scenarios

The main objective of the OnSSET modelling was to determine if and how inclusion of the productive uses of energy impacts the least cost electrification (LCE) technology mix for the different solutions. As such, two scenario were modelled, **Scenario 1** which involved household electrification without inclusion of PUE and **Scenario 2** which involved the electrification of households and electrification of PUE. The summary description of scenarios run is shown in Table 8. In both scenarios, the target was to electrify all urban households to Tier 4 electricity and to electrify all rural households to Tier 1 electricity by 2030, using the tiered access approach of the MTF (ESMAP, 2022). In both scenarios, fossil fuels were not considered as a source of energy given the climate change implications. Lastly, the least cost technology was selected nationwide without forcing any grid electrification.

Scenario Number	Scenario Name	Description	Key Parameters
1	Base Scenario	No productive uses included	Urban Target : Tier 4 Rural Target :Tier 1 No Fossil Fuels Considered Prioritization: Nationwide Least-Cost Approach
2	100% PUE	Productive Demand considered	Urban Target : Tier 4 Rural Target :Tier 1 No Fossil Fuels Considered Prioritization: Nationwide Least-Cost Approach

Table 8: Scenarios modelled

In terms of household electrification, the base year was set to be 2020, the intermediate year to be 2025 and the final year to be 2030. The target was to achieve 70% electrification by 2025 and 100% electrification by 2030. The urban households were to be electrified to tier 4 while the rural households were to be connected to tier 1.

6.1 Results of OnSSET Analysis

Three sets of results are discussed in this section. The first is on how inclusion of the PUE impacts the new installed capacity requirements, the second is on the investment cost required for the electrification and the third is on how inclusion of the PUE impacts the LCE technology mix.

6.1.1 Required new capacity for 100% Electrification

Adding the productive uses of energy increased the total required new capacity by 15.3% from 16,714kW to 19,279kW as shown in Table 14. As all the PUE activities are located in rural areas, adding these did not impact the demand in urban areas.

Required new capacity (kW)			
	Without PUE	**With PUE**	**Difference**
Rural areas	547	3,112	2,565
Urban areas	16,167	16,167	0
Total	16,714	19,279	2,565

Table 9: Required new capacity with and without inclusion of PUE

6.1.2 Electrification Technology Mix

Inclusion of PUE had a great impact on the electrification technology mix. Without PUE, the LCoE only involved grid and standalone PV systems. However, the inclusion of PUE showed 40 minigrids to be least cost technologies as shown in Table 10. The distribution of the LCE technologies with PUE included is as shown in Figure 6.

Electrification Technology Mix				
	Without PUE		**With PUE**	
	No. of Clusters	**Capacity (kW)**	**No. of Clusters**	**Capacity**
Grid	9,876	16,667	9,864	18,754
Minigrid	0	0	40	334
Standalone PV	1,153	47	1125	191

Table 10: Least cost electrification technology mix with and without inclusion of PUE

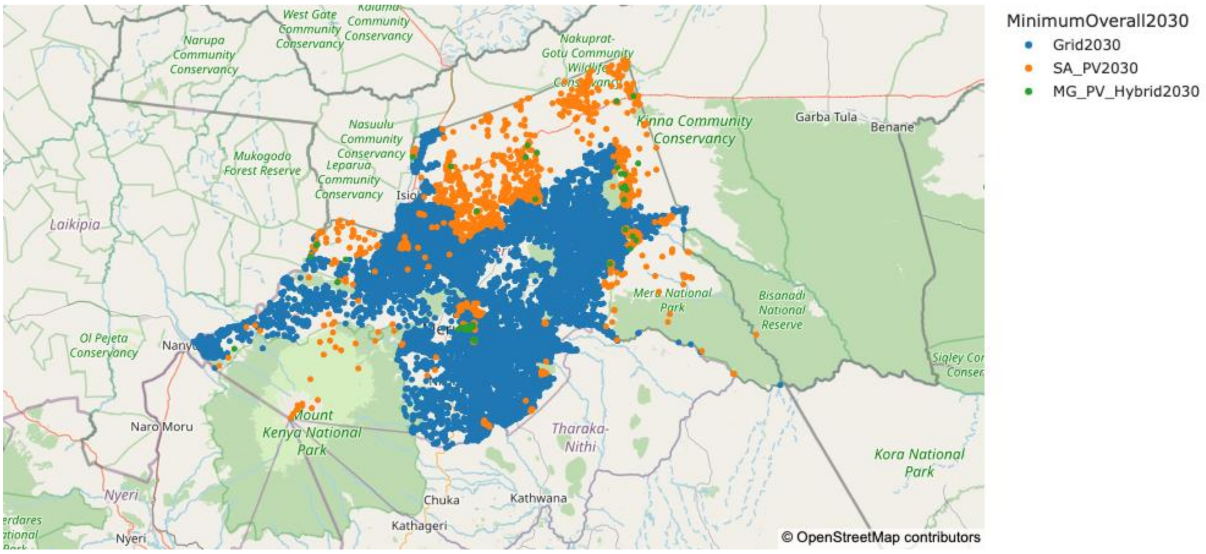

Figure 6: Least cost electrification technologies for Meru county

6.1.3 Investment Costs

The investment cost required for 100% electrification without PUE was USD 569.5 million. Adding PUE increases this cost by USD 4.1 million to 573.6 million as shown in Table 11. The addition of PUE reduces the cost per kW of new capacity by 12.7% from USD 34,075/kW to USD 29,753/kW. For the viable electrification technologies, the addition of PUE reduces the cost per unit as shown in Figure 7 – this reduction in the cost of the grid and that of the standalone system is brought about by the minigrids becoming viable as the demand grows.

Required Investment Cost (USD)			
	Without PUE	**With PUE**	**Difference**
Rural areas	502,306,059	506,419,397	4,113,338
Urban areas	67,196,544	67,196,544	0
Total	569,502,603	573,615,941	4,113,338

Table 11: Investment cost needed for 100% electrification of Meru county with and without inclusion of PUE

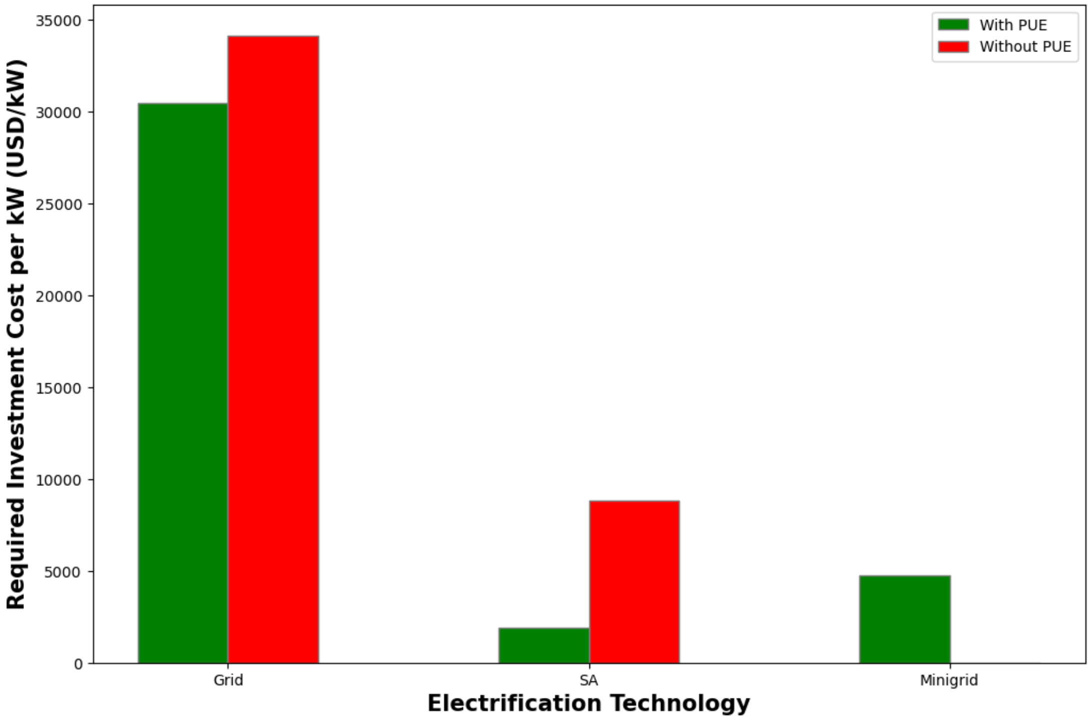

Figure 7: Investment cost required per kW of new capacity with and without inclusion of PUE.

7 Conclusions and recommendations

The modelling carried out shows, first, how a methodology can be developed, once the location and annual energy demand are identified, to aggregagte the energy components of the CEP solutions developed using the EDM to input productive uses of energy (PUE) in OnSSET modelling to give a more needs-based picture of county energy demand, and to support decision-making to inform the location and types of energy technology investments to make under the CEPs, in the context of INEP

A notable finding is that the inclusion of the PUE in the determination of LCE changes the electrification mix, and in this case makes mini-grids viable, reducing the average cost per kW of new capacity.

This approach could be replicated in other counties. For the modelling, it is critical that methodologies used to develop CEPs identify the power requirements and either the specific locations for the energy demand or sufficient information on target end users and location types to select eligible regions, to make the CEP outputs compatible with geospatial energy modelling tools such as OnSSET. This type of OnSSET modelling also requires identification of the costs of different technologies.

This modelling could be carried out to inform different stages of CEP planning but is perhaps best deployed to inform implementation planning, i.e. to determine what is the least cost electrification mix for deploying all different solutions developed across the county.

Again, it should be highlighted that, from the EDM perspective, the electrification investments identified need to be part of a holistic solution implementation comprising energy and non-energy interventions, in order for these investments to result in development impact and for the energy demand to be realised.

In terms of the OnSSET modelling tool itself, this could be strengthened by developing a new method for generating the OnSSET clusters that allow for productive uses located further from households to be their own clusters.

It is also important to note that how the OnSSET model calculates the final investment costs should be checked or “ground truthed” to determine what is the actual least cost electrification scenario given the local context.

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Annex 1: Geospatial datasets required for running OnSSET analysis

DATASET	DATA TYPE	PURPOSE	SOURCES
Administrative boundaries	Polygon	Delineates the boundaries of the analysis. Considered up to ward-level.	GADM (2023)
Settlements	Points	Location of settlements (hamlets, districts) and quantification of the current (base year) population. This dataset sets the basis of the analysis as it is directly connected to the electricity demand and the assignment of energy access goals. All other datasets are directly derived from this one.	Mwenda et al. (2022)
Hydro points	Points	Points showing potential mini/small hydropower potential.	Korkovelos (2017)
Power substations	Points	Used in order to assess grid extension suitability, the closer a settlement is to a substation, the easier it is to extend the grid to said settlement.	World Bank (2020)
Service transformers	Points	Can be used in order to calibrate electrified populations.	KPL (2022)
Medium-voltage lines (Existing)	Lines	To be used as a base for the grid extensions.	KPLC (2022)
High-voltage lines (Existing)	Lines	Can be used in order to calibrate electrified populations.	World Bank (2020)
High-voltage lines (Planned)	Lines	Planned high voltage lines are used in order to determine the cost of electrifying settlements using the grid in the end year.	World Bank (2020)
Roads	Lines	Main roads in the country. Used to specify grid extension suitability. The closer the settlement is to a road the easier it is to extend the grid to said settlement.	OSM (2023)
Global Tilted Irradiation (GTI)	Raster	Provides information about the total radiation received on a surface with defined tilt and azimuth (kWh/m^2/year). Used to identify the suitability of photovoltaic systems.	Global Solar Atlas (2023)
Wind speed	Raster	Provides information about the wind velocity (m/sec) over an area. Used to identify the suitability of wind power (using capacity factors).	Global Wind Atlas (2023)
Elevation	Raster	The elevation map is used in order to determine the terrain slope. Both the terrain slope and the elevation are used in	Nasa (2022)

		order to specify the grid extension suitability.	
Protected areas	Polygons	Protected areas imply penalties on the grid extension.	IUCN (2022)
Educational institutions	Points	Location of education facilities. This can be used if one wishes to include educational electricity consumption in their analysis.	GoK, Ministry of Education (2022)
Health facilities	Points	Location of health facilities. This can be used if one wishes to include electricity consumption in the health sector in their analysis.	HEALTH SITES & OSM (2022)

Annex 2: Techno-economic parameters used in OnSSET

Table 1 below shows the transmission and distribution costs used for the modelling. Table 2 shows various parameters for the grid. Table 3 shows the costs used for various electricity supply technologies. Table 4 shows the technology assumptions made in the analysis.

Parameter	Value	Unit	Source
High Voltage Line Capacity	132	KV	KPLC
High Voltage Line Cost(132kV)	90000	USD/KM	
Medium Voltage Line Cost(33kV)	30000	USD/KM	
Medium Voltage Line Capacity	33	KV	
Medium Voltage Line Max Length	50	km	
Medium Voltage Increase Rate	0.1	ratio	
Medium Voltage Amperage Limit(33kV 150m2)	487	Amperes	
Low Voltage Line Capacity	0.420	KV	
Low Voltage Line Max Length	0.6	km	
Low Voltage Line Cost	13700	USD/KM	
Service Transformer Type	50	kVA	
Service Transformer Cost[4]	3800	USD	
Max Nodes Per Service Transformer	300	NO	
High Voltage Low Voltage Transformer Cost(23MVA with tertiary)[5]	338800	USD	
High Voltage Medium Voltage Transformer Cost(23MVA 132/33)[6]	338800	USD	
Medium Voltage Low Voltage Transformer Cost(50kVA 33/0.42)[7]	3800	USD	
Medium Voltage Medium Voltage Transformer Cost(10MVA 33/11kV)[8]	162300	USD	

Table 1: Transmission & Distribution Costs

Parameter	Value	Unit	Source
Distribution Losses	24%[9]	%	KPLC
Connection Cost Per Household[10]	1300	USD	
Base To Peak Load Ratio	0.7	ratio	
Capacity Factor	0.6	ratio	
Tech Life	30	years	

Grid Penalty Ratio	1	ratio	
Grid Price = Grid Generation Cost	0.086	USD/kWh	
Diesel Price	0.85[11]	USD/litre	

Table 2: Centralized Grid Parameters

Parameter	**Value**	**Unit**
Standalone Diesel Capital Cost	938	USD/kW
Minigrid Diesel Capital Cost	721	USD/kW
Minigrid PV Capital Cost	3051	USD/kW
Minigrid Wind Capital Cost	3902	USD/kW
Minigrid Hydo Capital Cost	2902	USD/kW[12] [13]

Table 3: Energy Technology Costs

Plant type	**O&M costs (% of investment cost/year)**	**Life (years)**
Mini grid Wind	2%	20
Mini grid Hydro	2%	30
Mini grid PV	1.5%	20
Standalone PV Capital Cost 1 (systems under 20W)	2%	15
Standalone PV Capital Cost 2 (between 21-50W)	2%	15
Standalone PV Capital Cost 3 (between 51-100W)	2%	15
Standalone PV Capital Cost 4 (101-1000W)	2%	15
Standalone PV Capital Cost 5 (above 1kW)	2%	15

Table 4: Additional Technology Assumptions